STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Edition of December 1, 1914

STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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The following resolution regarding the Standardization Rules was adopted by the Board of directors July 10, 1914.

"*Resolved*, that the Rules reported by the Standards Committee be and hereby are adopted, subject to editorial revision by the Committee for the purpose of correcting errors and clarifying the real intent of the rules, the same to take effect December 1, 1914."

The necessary editorial corrections in compliance with the above resolution were made by the Standards Committee at its October and November meetings in 1914, and are here incorporated.

NOTE.

The Standards Committee takes this occasion to draw the attention of the membership to the value of suggestions based upon experience gained in the course of the application of the Rules to general practise.

Any suggestions looking toward improvement in the Rules should be communicated to the Secretary of the Institute for the guidance of the Standards Committee in the preparation of future editions.

The Standards Committee of 1914 which carried out the editing authorized by the above resolution was constituted as follows:—

A. E. KENNELLY, Chairman, Harvard University Cambridge, Mass.
C. A. ADAMS, Secretary, Harvard University, Cambridge, Mass.

JAMES BURKE, Erie, Pa.
W. A. DEL MAR, New York,
H. W. FISHER, Perth Amboy, N. J.
G. L. KNIGHT, Brooklyn, N. Y.
H. M. HOBART, Schenectady, N. Y.
F. B. JEWETT, New York.
P. JUNKERSFELD, Chicago, Ill.
W. L. MERRILL, Schenectady, N. Y.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, East Pittsburgh, Pa.
L. T. ROBINSON, Schenectady, N. Y.
E. B. ROSA, Washington, D. C.
C. E. SKINNER, East Pittsburgh, Pa.
J. M. SMITH, New York.
H. G. STOTT, New York.
P. H. THOMAS, New York.

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HISTORY OF THE STANDARDIZATION RULES

The first step taken by the Institute toward the standardization of electrical apparatus and methods was a topical discussion on "The Standardization of Generators, Motors and Transformers," which took place simultaneously in New York and Chicago on the evening of January 26, 1898. The discussion appears in the Institute TRANSACTIONS, Vol. XV, pages 3 to 32. The opinions expressed were generally favorable to the scheme of standardization of electrical apparatus, although some members feared that difficulties might arise. As a result of this discussion, a Committee on Standardization was appointed by the Council of the Institute, consisting of the following members:

FRANCIS B. CROCKER, *Chairman.*

CARY T. HUTCHINSON	CHARLES P. STEINMETZ
ARTHUR E. KENNELLY	LEWIS B. STILLWELL
JOHN W. LIEB, JR.	ELIHU THOMSON

After a careful consideration of the matter and consultation with the members of the Institute and interested parties generally, a "Report of the Committee on Standardization," was presented and accepted by the Institute, June 26, 1899. Those original rules appeared in the Institute TRANSACTIONS, Vol. XVI, pages 255 and 268.

As a result of changes and developments in the electric art, it was subsequently found necessary to revise the original report, this work being carried out by the following Committe on Standardization:

FRANCIS B. CROCKER, *Chairman.*

ARTHUR E. KENNELLY	CHARLES P. STEINMETZ
JOHN W. LIEB, JR.	LEWIS B. STILLWELL
C. O. MAILLOUX	ELIHU THOMSON

This revised report was adopted at the 19th Annual Convention at Great Barrington, Mass., on June 20, 1902, and appears in the Institute TRANSACTIONS, Vol. XIX, pages 1075 to 1092.

In consequence of still further change and development in electri al apparatus and methods, it was decided in September, 1905, that a second revision was needed, and the following Committee was appointed to do this work.

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

HENRY S. CARHART	CHARLES F. SCOTT
JOHN W. LIEB, JR.	CHARLES P. STEINMETZ
C. O. MAILLOUX	HENRY G. STOTT
ROBERT B. OWENS	S. W. STRATTON

This Committee held monthly meetings and carried on extensive correspondence with manufacturers, consulting and operating engineers and other interested parties, and as a result, presented its report at the 23d Annual Convention, held at Milwaukee, May 28–30, 1906. After considerable discussion the report was accepted and referred back to the Committee for amendment and rearrangement in form. It was then to be submitted to the Board of Directors for final adoption. In September, 1906, the following Standardization Committee was appointed:

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

A. W. BERRESFORD	CHARLES F. SCOTT
DUGALD C. JACKSON	CHARLES P. STEINMETZ
C. O. MAILLOUX	HENRY G. STOTT
ROBERT B. OWENS	S. W. STRATTON

ELIHU THOMSON

This Committee held monthly meetings, also sub-committee meetings, and carefully referred the rules as a whole, and each part of them, to the members of the Institute. The rules were also entirely rearranged as to form, and put in shape to facilitate ready reference to them and enable future revisions to be made without breaking up the logical arrangement. Thus amended the rules were submitted to the Board of Directors and approved by it on June 21, 1907. The Board also directed that the rules should be presented, as accepted by the Board, at the Annual Convention held at Niagara Falls, June 24 to 27, 1907, which action was taken by President Sheldon on June 26, 1907. By the Constitution which went into effect on June 10, 1907, this Committee has been made a standing Committee with the title " Standards Committee," consisting of nine members.

On August 12, 1910, the Board of Directors increased the size of the committee from nine to twelve members; on October 14 from twelve to fourteen, and on March 10, 1911, from fourteen to sixteen. The committee thus constituted is given below.

COMFORT A. ADAMS, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

H. W. BUCK	W. S. MOODY
GANO DUNN	R. A. PHILIP
H. W. FISHER	W. H. POWELL
H. B. GEAR	CHARLES ROBBINS
J. P. JACKSON	E. B. ROSA
W. L. MERRILL	CHARLES P. STEINMETZ
RALPH D. MERSHON	CALVERT TOWNLEY

This committee and several sub-committees held numerous meetings at which the general revision of the Standardization Rules of the Institute was considered. The complete Standardization Rules, as revised by this committee, were presented to and approved by the Board of Directors on June 27, 1911, at the Annual Convention held at Chicago, Ill.

The committee reappointed in August 1913 was enlarged by the Board of Directors in order to permit of sub-committees being formed on sectional parts of the work. The committee thus constituted is given as follows:

A. E. Kennelly, *Chairman.*
Comfort A. Adams, *Secretary.*

SUB-COMMITTEE No. 1. ON RATING.

H. M. Hobart, *Chairman.*

James Burke
W. C. L. Eglin
B. G. Lamme
W. A. Layman
W. L. Merrill
W. S. Moody
W. H. Powell
Charles Robbins
C. F. Scott
James M. Smith
Charles P. Steinmetz
J. Franklin Stevens
Philip Torchio

SUB-COMMITTEE No. 2. ON TELEGRAPH AND TELEPHONE STANDARDS.

F. B. Jewett, *Chairman.*

H. W. Fisher
F. F. Fowle
R. H. Marriott
J. H. Morecroft
J. M. Smith

SUB-COMMITTEE No. 3. ON RAILWAY STANDARDS.

W. A. Del Mar, *Chairman.*

F. W. Carter*
Hugh Hazelton*
E. R. Hill*
H. M. Hobart
William McClellan
Harold Pender
Martin Schreiber*
N. W. Storer*

SUB-COMMITTEE No. 4. ON NOMENCLATURE AND SYMBOLS.

Comfort A. Adams, *Chairman.*

Louis Bell
Dugald C. Jackson
M. G. Lloyd
H. Pender
E. B. Rosa
A. S. McAllister
R. H. Marriott

SUB-COMMITTEE No. 5. ON WIRES AND CABLES.

H. W. Fisher, *Chairman.*

Wallace Clark
W. A. Del Mar
W. C. L. Eglin
E. B. Rosa
C. E. Skinner
S. W. Stratton

SUB-COMMITTEE NO. 6. ON RATING AND TESTING OF CONTROL APPARATUS.

L. T. Robinson, *Chairman.*

Morton Arendt
R. A. Carle
C. H. Sharp
P. H. Thomas
Philip Torchio

Sub-committee No. 1 had representation from the National Electric Light Association (Messrs. L. L. Elden, G. L. Knight, J. E. Kearns, and E. P. Dillon), from the Association of Edison Illuminating Companies (Mr. P. Torchio) and from the Electric Power Club (Messrs. James Burke and J. M. Smith).

Sub-committee No. 3 (through Messrs. Schreiber and Del Mar, respectively worked in collaboration with the Committees of the American Electric Railway (Engineering) Association, and the Association of Railway Electrical Engineers.

*Sub-committee No. 3 was a joint subcommittee of the Standards Committee and of the Railway Committee. The members opposite whose names occurs an asterisk, represented the latter committee.

The following members, although not appointed on the Standards Committee, have materially contributed to its work and have attended its meetings:

Carl J. Fechheimer, E. D. Priest, R. B. Williamson, K. A. Pauly, L. F. Blume, C. Renshaw, G. H. Hill, C. J. Hixson.

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DEFINITIONS

NOTE. The following definitions are intended to be practically descriptive, and not scientifically rigid.

CURRENT, E.M.F. and POWER.

(The definitions of currents given below apply also, in most cases, to electromotive force, potential difference, magnetic flux, etc.

1 **A Direct Current** is a unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

2 **A Pulsating Current** is a current which pulsates regularly in magnitude. As ordinarily employed, the term refers to unidirectional current.

3 **A Continuous Current** is a practically non-pulsating direct current.

4 **An Alternating Current** is a current which alternates regularly in direction. Unless distinctly otherwise specified, the term "alternating current" refers to a periodic current with successive half waves of the same shape and area.

5 **An Oscillating Current** is a periodic current whose frequency is determined by the constants of the circuit or circuits.

6 **Cycle.** One complete set of positive and negative values of an alternating current.

7 **Electrical Degree.** The 360th part of a cycle.

8 **Period.** The time required for the current to pass through one cycle.

9 **Frequency.** The number of cycles or periods per second. The product of 2π by the frequency is called the *angular velocity* of the current.

10 **Root-Mean-Square or Effective Value.** The square root of the mean of the squares of the instantaneous values for one complete cycle. It is usually abbreviated r.m.s. Unless otherwise specified, the numerical value of an alternating current refers to its r.m.s. value. The r.m.s. value of a sinusoidal wave is equal to its maximum value divided by $\sqrt{2}$. The word "virtual" is sometimes used in place of r.m.s., particularly in Great Britain.

11 **Wave-Form or Wave-Shape.** The shape of the curve obtained when the instantaneous values of an alternating current are plotted against time in rectangular co-ordinates. The distance along the time axis corresponding to one complete cycle of values is taken as 2π radians, or 360 degrees. Two alternating quantities are said to have the same wave-form when their ordinates of corresponding phase (see **§ 13**) bear a constant ratio to each other. The wave-shape, as thus understood, is therefore independent of the frequency of the current and of the scale to which the curve is represented.

12 **Simple Alternating or Sinusoidal Current.** One whose wave-shape is sinusoidal.

Alternating-current calculations are commonly based upon the assumption of sinusoidal currents and voltages.

13 **Phase.** The distance, usually in angular measure, of the base of any ordinate of an alternating wave from any chosen point on the time axis, is called the phase of this ordinate with respect to this point. In the case of a sinusoidal alternating quantity, the phase at any instant may be represented by the corresponding position of a line or *vector* revolving about a point with such an angular velocity ($\omega = 2\pi f$) that its projection at each instant upon a convenient reference line is proportional to the value of the quantity at that instant.

14 **Non-Sinusoidal Quantities** are quantities that cannot be represented by vectors of constant length in a plane, and the following definitions of phase, active component, reactive component, etc., are not in general applicable. Certain " equivalent " values, as defined below, may, however, be used in many instances, for the purpose of approximate representation and calculation.

15 **Crest-Factor or Peak-Factor** is the ratio of the crest or maximum value to the r.m.s. value. The crest factor of a sine-wave is $\sqrt{2}$.

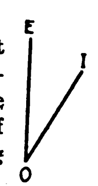
16 **Form Factor** is the ratio of the r.m.s. to the algebraic mean ordinate taken over a half-cycle beginning with the zero value. If the wave passes through zero more than twice during a single cycle, that zero shall be taken which gives the largest algebraic mean for the succeeding half-cycle. The form factor of a sine-wave is 1.11.

17 **Distortion Factor** of a wave is the ratio of the r.m.s. value of the first derivative of the wave with respect to time, to the r.m.s. value of the first derivative of the equivalent sine wave.

18 **Equivalent Sine Wave.** A sine wave which has the same frequency and same r.m.s. value as the actual wave.

*19 **Phase Difference: Lead and Lag.** When corresponding cyclic values of two sinusoidal alternating quantities of the same frequency occur at different instants, the two quantities are said to differ in phase by the angle between their nearest corresponding values, *e.g.*, the phase angle between their nearest ascending zeros or their positive maxima. That quantity whose maximum value occurs first in time is said to lead the other, and the latter is said to lag behind the former.

*20 **Counter-Clockwise Convention.** It is recommended that in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector, † as in the accompanying diagram, where OI represents the vector of a current in a simple alternating-current circuit lagging behind the vector OE of impressed e.m.f.



*21 **The Active or In-Phase Component** of the current in a circuit is that component which is in phase with the voltage across the circuit; similarly the active component of the voltage across a circuit is that component which is in phase with the current. The use of the term *energy component* for this quantity is disapproved.

*Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §12).

†See Publication 12 of the International Electrotechnical Commission (Report of Turin Meeting, Sept. 1911, p. 78).

*22 **The Reactive or Quadrature Component** of the current in a circuit is that component which is in quadrature with the voltage across the circuit; similarly the reactive component of the voltage across the circuit is that component which is in quadrature with the current. The use of the term *wattless component* for this quantity is disapproved.

*23 **Reactive Factor** is the sine of the angular phase difference between voltage and current; *i. e.*, the ratio of the reactive current or voltage to the total current or voltage.

*24 **Reactive Volt-Amperes.** The product of the reactive component of the voltage by the total current, or of the reactive component of the current by the total voltage.

*25 **Non-Inductive Load and Inductive Load.** A *non-inductive* load is a load in which the current is in phase with the voltage across the load. An *inductive* load is a load in which the current lags behind the voltage across the load. A *condensive* or *anti-inductive* load is one in which the current leads the voltage across the load.

26 **Power in an Alternating-Current Circuit** is the average value of the products of the coincident instantaneous values of the current and voltage for a complete cycle, as determined by a wattmeter.

27 **Volt-Amperes or Apparent Power.** The product of the r.m.s. value of the voltage across a circuit by the r.m.s. value of the current in the circuit. This is ordinarily expressed in kv-a.

28 **Power Factor** is the ratio of the power (cyclic average as defined in §26) to the volt-amperes. In the case of sinusoidal current and voltage, the power factor is equal to the cosine of their difference in phase.

29 **Equivalent Phase Difference.** When the current and e.m.f. in a given circuit are non-sinusoidal, it is customary, for purposes of calculation, to take as the "equivalent" phase difference the angle whose cosine is the power factor (see §28) of the circuit. There are cases, however, where this equivalent phase difference is misleading, since the presence of harmonics in the voltage wave, current wave, or in both, may reduce the power factor without producing a corresponding displacement of the two wave forms with respect to each other; *e.g.*, the case of an a-c. arc. In such cases the components of the equivalent sine waves, the equivalent reactive factor and the equivalent reactive volt-amperes may have no physical significance.

30 **Single-Phase.** A term characterizing a circuit energized by a single alternating e.m.f. Such a circuit is usually supplied through two wires. The currents in these two wires, counted positively outwards from the source, differ in phase by 180 degrees or a half-cycle.

31 **Three-Phase.** A term characterizing the combination of three circuits energized by alternating e.m.f.'s. which differ in phase by one-third of a cycle; *i.e.*, 120 degrees.

***Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §12).**

32 **Quarter-Phase, also called Two-Phase.** A term characterizing the combination of two circuits energized by alternating e.m.f's. which differ in phase by a quarter of a cycle; *i.e.*, 90 degrees.

33 **Six-Phase.** A term characterizing the combination of six circuits energized by alternating e.m.f's. which differ in phase by one sixth of a cycle; *i.e.*, 60 degrees.

34 **Polyphase** is the general term applied to any system of more than a single phase. This term is ordinarily applied to symmetrical systems.

Per Cent Drop.

35 In electrical machinery, the ratio of the **internal resistance drop** to the terminal voltage, expressed in per cent, is called the "*per cent resistance drop.*"

36 Similarly the ratio of the **internal reactance drop** to the terminal voltage, expressed in per cent, is called the "*per cent reactance drop.*"

37 Similarly the ratio of the **internal impedance drop** to the terminal voltage, expressed in per cent, is called the "*per cent impedance drop.*"

Unless otherwise specified, these per cent drops shall be referred to rated load and rated power factor.

38 In the case of transformers, the per cent drop will be the primary drop (reduced to secondary turns) plus the secondary drop, in per cent of secondary terminal voltage.

39 In the case of induction motors, it is advantageous to express the drops in per cent of the internally induced e.m.f.

40 **The Load Factor** of a machine, plant or system is the ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day, a month, or a year, and the maximum is taken over a short interval of the maximum load within that period.

In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load-factor. The proper interval and period are usually dependent upon local conditions and upon the purpose for which the load factor is to be used.

41 **Plant Factor** is the ratio of the average load to the rated capacity of the power plant.

42 **The Demand** of an installation or system is the load which it puts on the source of supply, as measured at the receiving terminals. The demand may be as specified, contracted for, or used. It may be expressed either in kilowatts, kilovolt-amperes, amperes or other suitable units.

43 **Maximum Demand** of an installation or system is its greatest demand, as measured not instantaneously but over a suitable and specified interval, such as a "five-minute maximum demand."

44 **Demand Factor** is the ratio of the maximum demand of any system or part of a system to the total connected load of the system, or of the part of system, under consideration.

45 **Diversity Factor** is the ratio of the sum of the maximum power demands of the subdivisions of any system or parts of a system

to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

46 **Connected Load.** The combined continuous rating of all the receiving apparatus on consumers' premises connected to the system or part of the system under consideration.

47 **The Saturation Factor** of a machine is the ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the excitation existing at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

48 **The Percentage of Saturation** of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is independent of the scales selected for excitation and voltage. This ratio, as a fraction, is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity, or if f be the saturation factor and p the percentage of saturation,

$$p = 100\left(1 - \frac{1}{f}\right)$$

49 **Magnetic Degree.** The 360th part of the angle subtended, at the axis of a machine, by a pair of its field poles. One **mechanical degree** is thus equal to as many magnetic degrees as there are pairs of poles in the machine.

50 **The Variation in Prime Movers** which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 degrees.

51 **The Variation in Alternators** or alternating-current circuits in general, is the maximum angular displacement, expressed in electrical degrees, (one cycle = 360 deg.) of corresponding ordinates of the voltage wave and of a wave of absolutely constant frequency equal to the average frequency of the alternator or circuit in question, and may be due to the variation of the prime mover.

52 **Relations of Variations in Prime Mover and Alternator.** If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and $p\ n$ times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

53 **The Pulsation in Prime Movers,** or in the alternator connected thereto, is the ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

54 **Capacity.** The two different senses in which this word is used sometimes lead to ambiguity. It is therefore recommended that whenever such ambiguity is likely to arise, the descriptive term *power capacity* or *current capacity* be used, when referring to the power or current which a device can safely carry, and that the term "*Capacitance*" be used when referring to the electrostatic capacity of a device.

55 **A Resistor** is a device, heretofore commonly known as a resistance, used for the operation, protection, or control of a circuit or circuits. See § 386.

56 **A Reactor** is a coil, winding or conductor commonly known as a reactance coil or choke coil, possessing inductance, the reactance of which is used for the operation, protection or control of a circuit or circuits. See also § 120.

57 **The Efficiency** of an electrical machine or apparatus is the ratio of its useful output to its total input.

58 **SYMBOLS AND ABBREVIATIONS.**

Name of Quantity.	Symbol for the Quantity.	Unit.	Abbreviation for the Unit.
Electromotive force, abbreviated e.m.f.	E, e	volt	....
Potential difference, abbreviated p.d.	V, v or E, e	"	....
Voltage	E, e or V, v	"	....
Current	I, i	ampere	....
Quantity of electricity	Q, q	coulomb or ampere-hour	....
Power	P, p	watt	....
Electrostatic flux	Ψ	....	....
Electrostatic flux density	D	....	....
Electrostatic field intensity	F		
Magnetic flux	Φ, φ	maxwell*	....
Magnetic flux density	$B, \mathcal{B}$	gauss*	....
Magnetic field intensity	$H, \mathcal{H}$	gilbert per centimeter or gauss†	gilbert per cm. ....
Magnetomotive force, abbreviated m.m.f.	$\mathcal{F}$	gilbert*	....
Intensity of magnetization	J	....	....
Susceptibility	$\kappa = J/H$	....	....
Permeability	$\mu = B/H$	....	....

* An additional unit for m. m. f. is the "ampere-turn", for flux the "line", for magnetic flux-density "maxwells per sq. in."

† The gauss is provisionally accepted for the present as the name of both the unit of field intensity and flux density on the assumption that permeability is a simple numeric.

Resistance	R, r	ohm	....
Reactance	X, x	"	....
Impedance	Z, z	"	....
Conductance	g	mho	....
Susceptance	b	"	....
Admittance	Y, y	"	....
Resistivity	ρ	* ohm-centimeter	ohm-cm.
Conductivity	γ	* mho per centimeter	mho per cm.
Dielectric constant	ϵ or k	....	....
Reluctance	$\mathcal{R}$	....	....
Capacitance (Electrostatic capacity)	C	farad	....
Inductance (or coefficient of self induction)	L	henry	....
Mutual Inductance (or coefficient of mutual induction)	M	henry	....
Phase displacement	θ, φ	degree or radian	°
Frequency	f	cycle per second	~
Angular velocity	ω	radians per second	....
Velocity of rotation	n	revolutions per second	rev. per sec.
Number of conductors or turns	N	convolutions or turns of wire	
Temperature	T, t, θ	degree centigrade	°C.
Energy, in general	U or W	joule or watt-hour	....
Mechanical work	W or A	joule or watt-hour	....
Efficiency	η	per cent	....
Length	l	centimeter	cm.
Mass	m	gram	g.
Time	t	second	sec.
Acceleration due to gravity	g	centimeters per second per second	cm. per sec. per sec.
Standard acceleration due to gravity (at about 45 deg. latitude and sea level) equals 980.665†	g_0	centimeters per second per second	cm. per sec. per sec.

**Note.* The numerical values of these quantities are *ohms resistance* and *mhos conductance* between two opposite faces of a cm. cube of the material in question, but the correct names are as given, not ohms and mhos per cm. cube as commonly stated.

†This has been the accepted standard value for many years and was formerly considered to correspond accurately to 45° Latitude and sea level. Later researches, however, have shown that the most reliable value for 45° and sea-level is slightly different; but this does not affect the standard value given above.

59 E_m, I_m and P_m should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see §10) and P for the average value or active power. These distinctions are not necessary in dealing with continuous-current circuits. In print, vector quantities should be represented by bold-face capitals.

CLASSIFICATION OF MACHINERY.

60 The machinery under consideration in these rules may be classified in various ways, these various classifications overlapping or interlocking in considerable degree. Briefly, they are Direct-Current or Alternating-Current, Rotating or Stationary. Under Rotating Apparatus there are two principal classifications: *First*, according to the function of the machines; Motors, Generators, Boosters, Motor-Generators, Dynamotors, Double-Current Generators, Converters and Phase Modifiers; Second, according to the type of construction or principle of operation; Commutating, Synchronous, Induction, Unipolar, Rectifying. Obviously some of these groups could be rationally included in either classification, *e.g.*, Motor-Generators and Rectifying Machines.

In the following, the self-evident definitions are for the most part omitted.

ROTATING MACHINES.

FUNCTIONAL CLASSIFICATION OF ROTATING MACHINES.

61 A **Generator** is a machine which transforms mechanical power into electrical power.

62 A **Motor** transforms electrical power into mechanical power.

63 A **Booster** is a generator inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

64 A **Motor-Generator** is a transforming device consisting of a motor mechanically coupled to one or more generators.

65 A **Dynamotor** is a transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

66 A **Direct-Current Compensator** or **Balancer** comprises two or more similar direct-current machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple-wire system of distribution, for the purpose of maintaining the potentials of the intermediate wires of the system, which are connected to the junction points between the machines.

67 A **Double-Current Generator** supplies both direct and alternating currents from the same armature-winding.

68 A **Converter** is a machine employing mechanical rotation in changing electrical energy from one form into another. There are several types, of converters as follows:

69 **A Direct-Current Converter** converts from a direct current to a direct current, usually with a change of voltage. Such a machine may be either a motor-generator or a dynamotor.

70 **A Synchronous Converter** (sometimes called a Rotary Converter) converts from an alternating to a direct current, or vice-versa. It is a synchronous machine with a single closed-coil armature.

71 **A Cascade Converter,** also called a **Motor Converter,** is a combination of an induction motor with a synchronous converter, the secondary circuit of the former feeding directly into the armature of the latter; *i.e.*, it is a synchronous converter concatenated with an induction motor.

72 **A Frequency Converter** converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases, or in the voltage.

73 **A Rotary Phase-Converter** converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

74 **A Phase-Modifier,** also called *a Phase-Advancer*, is a machine which supplies reactive volt-amperes to the machine; *e.g.* to an induction motor, or to the system to which it is connected. Phase modifiers may be either synchronous or asynchronous.

75 **A Synchronous Phase-Modifier,** sometimes called a Synchronous Condenser, is a synchronous motor, running either idle or with load, the field excitation of which may be varied so as to modify the power-factor of the system, or through such modification to influence the load voltage. The function of a Synchronous Phase-Modifier is to supply reactive volt-amperes to the system with which it is connected.

CONSTRUCTIONAL CLASSIFICATION OF ROTATING MACHINES

Commutating Machines

76 **Direct-Current Commutating Machines** comprise a magnetic field of constant polarity, an armature, and a multisegmental commutator connected therewith. These include: Direct-Current Generators; Direct-Current Motors; Direct-Current Boosters; Direct-Current Motor-Generators and Dynamotors; Direct-Current Compensators or Balancers; and Arc Machines; either with or without commutating poles.

77 **Alternating-Current Commutating Machines*** comprise a magnetic field of alternating polarity, an armature, and multisegmental commutator connected therewith.

*Definitions of a-c. commutator-motors have not yet been agreed upon. The differences of opinion are fundamental and relate to the whole system to be employed in naming the numerous types. One example of this difference is in connection with the definition of the term " Repulsion-Motor", some desiring to extend its use to cover all a.c. commutator motors with short-circuited brushes, and others to substitute more systematic names for the various species of short-circuited brush motors.

78 **Synchronous Commutating Machines** include synchronous converters, cascade-converters, and double-current generators.

SYNCHRONOUS MACHINES

79 Comprise a constant magnetic field and an armature receiving or delivering alternating-currents in synchronism with the motion of the machine; *i.e.*, having a frequency strictly proportional to the speed of the machine. They may be sub-divided as follows:

80 **An Alternator** is a synchronous alternating-current generator, either single-phase or polyphase.

81 **A Polyphase Alternator** is a polyphase synchronous alternating-current generator, as distinguished from **a singlephase alternator.**

82 **An Inductor Alternator is a Synchronous Alternator** in which both field and armature windings are stationary and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them. It may be either singlephase or polyphase.

83 **A Synchronous Motor** is a machine structurally identical with a synchronous alternator, but operated as a motor.

INDUCTION MACHINES

84 Include apparatus wherein the primary and secondary windings rotate with respect to each other; *i.e.*, induction motors, induction generators, certain types of frequency converters and certain types of rotary phase-converters.

85 **An Induction Motor** is an alternating-current motor, either singlephase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding receives power from the primary by electromagnetic induction.

86 **An Induction Generator** is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

87 **Unipolar or Acyclic Machines** are direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

SPEED CLASSIFICATION OF MOTORS.

88 **Motors** may, for convenience, be classified with reference to their speed characteristics as follow:

89 *a.* **Constant-Speed Motors,** in which the speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

90 *b.* **Multispeed Motors** (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as motors with two armature windings, or induction motors, in which the number of poles is changed by external means.

91 *c.* **Adjustable-Speed Motors,** in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of speed variation.

92 *d.* **Varying-Speed Motors,** or motors in which the speed varies with the load, ordinarily decreasing when the load increases; such as series motors, compound-wound motors, and series-shunt motors. As a sub class of varying-speed motor, may be cited, adjustable varying-speed motors, or motors in which the speed can be varied over a considerable range at any given load, but when once adjusted, varies with the load; such as compound-wound motors arranged for adjustment of speed by varying the strength of the shunt field.

CLASSIFICATION OF ROTATING MACHINES RELATIVE TO THE DEGREE OF ENCLOSURE OR PROTECTION

93 The following types are recognized:

Open
Protected
Semi-enclosed
Enclosed
Separately ventilated
Water-cooled
Self-ventilated
Drip-proof
Moisture-resisting
Submersible
Explosion-proof
Explosion-proof slip-ring enclosure

94 An **"open" machine** is of either the pedestal-bearing or end-bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.

95 A **"protected" machine** is one in which the armature, field coils, and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

96 A **"semi-enclosed" machine** is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding ½ of a square inch (3.2 sq. cm.) in area.

97 An **"enclosed" machine** is so completely enclosed by integral or auxiliary covers as to prevent a circulation of air between the inside and outside of its case, but not sufficiently tight to be termed air-tight.

98 A **"separately ventilated" machine** has its ventilating air supplied by an independent fan or blower external to the machine.

99 A **"water-cooled" machine** is one which mainly depends on water circulation for the removal of its heat.

100 A **"self-ventilated" machine** is a semi-enclosed machine, differing from a separately ventilated machine only in having its ventila-

ting air circulated by a fan, blower, or centrifugal device integral with the machine.

If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.

101 A **"drip-proof" machine** is one so protected as to exclude falling moisture or dirt. A "drip proof" machine may be either "open" or "semi-enclosed", if it is provided with suitable protection integral with the machine, or so enclosed as to exclude effectively falling solid or liquid material.

102 A **moisture-resisting machine** is one in which all parts are treated with moisture-resisting material. Such a machine shall be capable of operating continuously or intermittently in a very humid atmosphere, such as in mines, evaporating rooms, etc.

103 **A "submersible" machine** is a machine capable of withstanding complete submersion for four hours without injury.

104 **An "explosion-proof" machine** is a machine in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the flame to any inflammable gas outside it.

105 An induction motor in which the slip rings and brushes alone are included within an explosion-proof case should not be described as an explosion-proof machine, but as a machine "with **explosion-proof slip-ring enclosure.**"

STATIONARY INDUCTION APPARATUS

107* **Stationary Induction Apparatus** changes electric energy to electric energy through the medium of magnetic energy without mechanical motion. It comprises several forms, distinguished as follows:

108 **Transformers**, in which the primary and secondary windings are ordinarily insulated one from another.

109 The terms **"high-voltage"** and **"low-voltage"** are used to distinguish the winding having the greater from that having the lesser number of turns. The terms **"primary"** and **"secondary"** serve to distinguish the windings in regard to energy flow, the primary being that which receives the energy from the supply circuit, and the secondary that which receives the energy by induction from the primary.

110 The **rated current of a constant-potential transformer** is that secondary current which, multiplied by the rated-load secondary voltage, gives the kv-a. rated output. That is, a transformer of given kv-a. rating must be capable of delivering the rated output at rated secondary voltage, while the primary impressed voltage is increased to whatever value is necessary to give rated secondary voltage.

The rated primary voltage of a constant-potential transformer is the rated secondary voltage multiplied by the turn ratio.

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* ¶ 106 omitted.

111 The **ratio of a transformer,** unless otherwise specified, shall be the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding; *i.e.*, the "turn-ratio."

112 The **voltage ratio** of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage under specified conditions of load.

113 The "**current ratio**" of a current-transformer is the ratio of r.m.s. primary current to r.m.s. secondary current under specified conditions of load.

114 The "**marked ratio**" of an instrument transformer is the ratio which the apparatus is designed to give under average conditions of use. When a precise ratio is required, it is necessary to specify the voltage, frequency, load and power factor of the load.

115 **Auto-transformers** have a part of their turns common to both primary and secondary circuits.

116 **Voltage Regulators** have turns in shunt and turns in series with the circuit, so arranged that the voltage ratio of the transformation or the phase relation between the circuit-voltages is variable at will. They are of the following three classes:

117 **Contact Voltage Regulators,** in which the number of turns in one or both of the coils is adjustable.

118 **Induction Voltage Regulators,** in which the relative positions of the primary and secondary coils are adjustable.

119 **Magneto Voltage Regulators,** in which the direction of the magnetic flux with respect to the coils is adjustable.

120 **Reactors** or **Reactance-Coils,** also called **Choke Coils**; a form of stationary induction apparatus used to supply reactance or to produce phase displacement. See also **§56.**

INSTRUMENTS

121 **An Ammeter** is an instrument for measuring current, indicating in amperes.

122 **A Voltmeter** is an instrument for measuring difference of potential, indicating in volts.

123 **A Wattmeter** is an instrument for measuring electrical power, indicating in watts.

124 **Recording Ammeters, Voltmeters, Wattmeters, etc.,** are instruments which record graphically upon a time-chart the values of the quantities they measure.

125 **A Watt-hour Meter** is an instrument for registering watt-hours. This term is to be preferred to the term "integrating wattmeter.'

126 **A Line-Drop Voltmeter Compensator** is a device in connection with a voltmeter, which causes the latter to indicate the voltage at some distant point of the circuit.

127 **A Synchroscope, sometimes called a Synchronism Indicator,** is a device which, in addition to indicating synchronism, shows whether the machine to be synchronized is fast or slow.

STANDARDS FOR ELECTRICAL MACHINERY

128 The expressions "machinery" and "machines" are here employed in a general sense in order to obviate the constant repetition of the words "machinery or induction apparatus."

129 All temperatures are to be understood as centigrade.

130 The expression "capacity" is to be understood as indicating "capability" except where specifically qualified as, for instance, in the case of allusions to electrostatic capacity, *i.e.*, capacitance.

131 Wherever special rules are given for any particular type of machinery or apparatus (such as switches, railway motors, railway substation machinery, etc.) these special rules shall be followed, notwithstanding any apparent conflict with the provisions of the more general sections. In the absence of special rules on any particular point, the general rules on this point shall be followed.

132 **Objects of Standardization.** To ensure satisfactory results, electrical machinery should be specified to conform to the Institute Standardization Rules in order that it shall comply, in operation, with approved limitations in the following respects, so far as they are applicable.

Operating temperature
Mechanical strength
Commutation
Insulation strength
Efficiency
Power factor
Wave shape
Regulation

133 **Capacity of an Electrical Machine.** So far as relates to the purposes of these Standardization Rules, the Institute defines the Capacity of an Electrical Machine as the load or task of which it is capable for a specified time (or continuously), without exceeding in any respect the limitations herein set forth.

Except where otherwise specified, the capacity of an electrical machine shall be expressed in terms of its *output*. For exceptions see **§140** and **417**.

134 **Rating of an Electrical Machine.** Capacity should be distinguished from Rating. The Rating of a machine is the output marked on the Rating Plate, and shall be based on, but shall not exceed, the maximum* load which can be taken from the machine under prescribed conditions of test. This is also called the rated output.

135 **A. I. E. E. and I. E. C. Ratings.** When the prescribed conditions of test are those of the A. I. E. E. Standardization Rules, the rating of the machine is the Institute Rating. (See **§313** (a)). When the prescribed conditions of the test are those of the I. E. C. Rules, the rating of the machine is the I. E. C. rating. A machine so rated in either case may bear a distinctive sign upon its rating plate.

*The term "maximum load" does not refer to loads applied solely for mechanical, commutation, or similar tests.

136 **Standard Temperature and Barometric Pressure for Institute Rating.** The Institute Rating of a machine shall be its capacity when operating with a cooling medium of the ambient temperature of reference (40° for air or 25° for water, see **§153** and **157**) and with barometric conditions within the range given in **§156**. See **§168.**

UNITS IN WHICH RATING SHALL BE EXPRESSED

137 In the case of **Direct-Current Generators,** the rating shall be expressed in kilowatts (kw.) available at the terminals.

138 In the case of **Alternators** and **Transformers,** the rating shall be expressed in kilovolt-amperes (kv-a.) available at the terminals, at a specified power factor. The corresponding kilowatts should also preferably be stated.

139 In the case of **Motors,** it is strongly recommended that the rating shall be expressed in kilowatts* (kw.) available at the shaft. (An exception to this rule is made in the case of Railway motors, which for some purposes are also rated by their *input*, see **§417.**)

140 **Auxiliary machinery,** such as regulators, phase controllers, resistors, reactors, balancer sets, stationary and synchronous condensers, etc., shall have their ratings appropriately expressed. It is essential to specify also the voltage of the circuits on which the machinery may appropriately be used.

KINDS OF RATING

141 There are various kinds of rating such as:

142 **Continuous Rating.** A machine rated for continuous service shall be able to operate continuously at its rated output, without exceeding any of the limitations referred to in **§132.**

143 **Short-Time Rating.** A machine rated for short- ime service (*i.e.* service including runs alternating with stoppages of sufficient duration to ensure substantial cooling,) shall be able to operate at its rated output during a limited period, to be specified in each case, without exceeding any of the limitations referred to in **§132.** Such a rating is a **short-time rating.**

144 **Nominal Ratings.** For railway motors and railway substation machinery, certain nominal ratings are employed. See **§391** and **415.**

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*Since the input of machinery of this class is measured in electrical units and since the output has a definite relation to the input, it is logical and desirable to measure the delivered power in the same units as are employed for the received power. Therefore, the output of motors should be expressed in kilowatts instead of in horse power. However, on account of the hitherto prevailing practise of expressing mechanical output in horse power, it is recommended that for machinery of this class the rating should, for the present, be expressed both in kilowatts and in horse power; as follows:

kw.————approx. equiv. h.p.————

The horse power rating of a motor may for practical purposes, be taken as 4/3 of the kilowatt rating.

In order to lay stress upon the preferred future basis, it is desirable that on Rating Plates, the Rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

145 **Duty-Cycle Operation.** Many machines are operated on a cycle of duty which repeats itself with more or less regularity. For purposes of rating, either a continuous or a short-time "equivalent load" may be selected which shall simulate as nearly as possible the thermal conditions of the actual duty cycle.

146 **Standard durations of equivalent tests** shall be for machines operating under specified duty-cycles:

5 minutes
10 "
30 "
60 "
120 "
and continuous.

Of these the first five are short-time ratings selected as being thermally equivalent to the specified duty cycle.

When, for example, a short-time rating of 10 minutes duration is adopted, and the thermally equivalent load is 25 kw. for that period, then such a machine shall be stated to have a 10-minute rating of 25 kw.

147 In every case the equivalent short-time test shall commence only when the windings and other parts of the machine are **within 5°C of the ambient temperature** at the time of starting the test.

148 In the absence of any specification as to the kind of rating, the continuous rating shall be understood.*

Machines marked in accordance with **§135** shall be understood to have a continuous rating unless otherwise marked in accordance with **§146.**

HEATING AND TEMPERATURE

149 **Temperature Limitations of the Capacity of Electrical Machinery.** The capacity, so far as relates to temperature, is usually limited by the maximum temperature at which the materials in the machine, especially those employed for insulation, may be operated for long periods without deterioration. When the safe limits are exceeded, deterioration is rapid. The insulating material becomes permanently damaged by excessive temperature, the damage increasing with the length of time that the excessive temperature is maintained, and with the amount of excess temperature, until finally the insulation breaks down.

150 The result of operating at temperatures in excess of the safe limit is to shorten the life of the insulating material. This shortening of life is, in certain special cases, warranted, when necessary for obtaining some other desirable result, as, for example, in some instances of railway motors, in providing greater power within a limited space. See **§419.** Further instances may also be noted in the cases of contactors, controllers, arc-lamp magnet windings, etc., designed and constructed for operation at relatively high temperatures.

***An exception is made in the case of machines for railway service, where in the absence of any specification as to the kind of rating, the "nominal rating" as defined in §391 and 416 shall be understood.**

151 There does not appear to be any advantage in operating at lower temperatures than the safe limits, so far as the life of the insulation is concerned. Insulation may break down from various causes, and when these breakdowns occur, it is not usually due to the temperature at which the insulation has been operated, provided the safe limits have not been exceeded.

152 **The Ambient Temperature** is the temperature of the fluid or fluids which, coming into contact with the heated parts of a machine, carries off its heat convectively.

The cooling fluid may either be led to the machine through ducts, or merely surround the machine freely. In the former case the ambient temperature is to be measured at the intake of the machine. In the latter case see **§163.**

153 **Ambient Temperature of Reference for Air.** The standard ambient temperature of reference, when the cooling medium is air, shall be 40°C.

154 The permissible rises in temperature given in column 2 of the table in **§188** have been calculated on the basis of the standard ambient temperature of reference, by subtracting 40° from the highest temperatures permissible, which are given in column 1 of the same table.

155 A machine may be tested at any convenient ambient temperature, but whatever be the value of this ambient temperature, the permissible rises of temperature must not exceed those given in column 2 of the table in **§188.**

156 **Altitude.** Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters (3300 feet.) For machinery operating at an altitude of 1000 meters or less, a test at any altitude less than 1000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. When a machine is intended for service at altitudes above 1000 meters (3300 ft.) the permissible temperature rise at sea level, until more nearly accurate information is available, shall be reduced by 1 per cent for each 100 meters (330 ft.) by which the altitude exceeds 1000 meters. Water-cooled oil transformers are exempt from this reduction.

157 **Ambient Temperature of Reference for Water-Cooled Machinery.** For water-cooled machinery, the standard temperature of reference for incoming cooling water shall be 25° C, measured at the intake of the machine.

158 **In Testing Water-Cooled Transformers,** it is important, especially for the smaller sizes, to maintain the temperature of the ingoing water within 5°C. of the surrounding air. Where this is impracticable, the reference ambient temperature should be taken as that indicated by the resistance of the windings, when a disconnected transformer is being

supplied with the normal amount of cooling water and the temperature of the windings has become constant.

159 **Machinery Cooled by Air led to the machine from a distance through ventilating ducts.** In this case the temperature of the ingoing air shall be measured at the intake of the machine. The ambient temperature shall be determined in the manner specified in **§158** for water-cooled transformers.

160 The above method is not applicable to the case of *rotating machines.* For these a conventional weighted mean shall be employed, a weight of four being given to the temperature of the circulating air supplied through ducts (see §152), and a weight of one to the surrounding room air. The temperature of the circulating air shall be held within 10 °C. of the temperature of the surrounding room air throughout the test.

161 **Machines Cooled by Other Means.** For machines cooled by other means, special rules are necessary.

162 **Outdoor Machinery Exposed to Sun's Rays.**
Outdoor machinery not protected from the sun's rays at times of heavy load, must receive special consideration.

163 **Measurement of the Ambient Temperature During Tests of Machinery.**
The ambient temperature is to be measured by means of several thermometers placed at different points around and half-way up the machine at a distance of 1 to 2 meters (3 to 6 feet), and protected from drafts, and abnormal heat radiation, preferably as in **§165.**

164 The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above) taken at equal intervals of time during the last quarter of the duration of the test.

165 Inorder to avoid **errors due to the time lag** between the temperature of large machines and the variations in the ambient air, all reasonable precautions must be taken to reduce these variations and the errors arising therefrom. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, in a suitable heavy metal cup. This can be made to respond to various rates of change, by proportioning the amount of oil to the metal in the containing cup. A convenient form for such an oil-cup consists of a massive metal cylinder with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb well immersed. The larger the machine under test, the larger should be the metal cylinder employed as an oil-cup in the determination of the ambient temperature. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm. in diameter and 50 mm. high (1 in. in diameter and 2 in. high).

166 **In Testing Transformers** and sometimes in other machines, it will often be desirable to avoid errors due to time lag in temperature changes by

employing an idle unit of the same size and subjected to the same conditions of cooling as the unit under test, for obtaining the ambient temperature as described in **§ 158** and **§ 159**.

167 Where **machines are partly below the floor line** in pits, the temperature of the rotor shall be referred to a weighted mean of the pit and room temperatures, the weight of each being based on the relative proportions of the machine in and above the pit. Parts of the stator constantly in the pit shall be referred to the ambient temperature in the pit.

168 **Corrections for the Deviation of the Ambient Temperature, at the time of test, from the reference value of 40°C.** In view of numerous experiments which have shown that the effect on the temperature rise of the precise value of the ambient temperature at the time of test, is small, obscure and of doubtful direction, no correction shall be made for ambient temperature deviations from the standard value of 40°C. It is, however, desirable that tests should be conducted at ambient temperatures not lower than 25°C. Exception to this rule is made in the case of air-blast transformers, in which, if the ingoing air temperature during the test differs from 40°C, correction on account of difference in resistance and difference in convection shall be made by changing the "observable" temperature rise of the windings by 0.5% for each degree centigrade. Thus with a room temperature of **30** ° C. the "observable" rise of temperature shall be increased by 5 per cent, and with a room temperature of 15 ° C., the "observable" rise of temperature shall be increased by 12.5 per cent.

169 **Duration of Heat Run.** For practical purposes, the duration of a test of a machine for continuous service shall be prolonged until the difference between the temperature of the machine and the ambient temperature is practically constant. Temperature measurements, when possible, shall be taken during operation, as well as when the machine is stopped. The highest figures thus obtained shall be adopted. In order to abridge the long heating period, in the case of large machines, reasonable overloads of current during the preliminary period are suggested for them.

OPERATING TEMPERATURES

170 The actual temperatures attained in the different parts of a machine, and not the rises in temperature, affect the life of the insulation of the machine. (See **§149** to **151**).

171 The temperatures in the different parts of a machine which it is desired to ascertain, are the maximum temperatures reached in those parts.

172 As it is usually impossible to determine the maximum temperature attained in insulated windings, it is convenient to apply a correction to the observable temperature, to approximate the difference between the actual maximum temperature and the observable temperature by the method used. This correction or margin of security is provided to cover the errors due to fallibility in the location of the measuring devices, as well as inherent inaccuracies in measurement and methods.

TEMPERATURE MEASUREMENTS

173 In determining the temperature of different parts of a machine, three methods will be considered. One or other of these methods, as set forth below, will usually be appropriate for commercial measurements on any particular type of machine.

174 **Method No 1. Thermometer Method.**
This method consists in the determination of the temperature by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest accessible part of the *completed* machine, as distinguished from the thermocouples or resistance coils imbedded in the machine as described under Method No. 3.

175 When Method No.1 is used, the hottest-spot temperature for windings shall be estimated by adding a hottest-spot correction of 15°C to the highest temperature observed, in order to allow for the impossibility of locating any of the thermometers at the hottest spot.

176 *Exception.* In cases where the thermometer is applied directly to the surfaces of a bare winding, such as an edgewise strip conductor, or a cast copper winding, a hottest-spot correction of 5°C. instead of 15°C shall be made. For bare metallic surfaces not forming part of a winding, no correction is to be applied.

177 **Method No. 2. Resistance Method.**
This method consists in the measurement of the temperature of windings by their increase in resistance, corrected* to the instant of shut-down when necessary. In the application of this method careful thermometer measurements must also be made whenever practicable without disassembling the machine†, in order to increase the probability of revealing the highest observable temperature. Whichever method yields the higher temperature, that temperature shall be taken as the "highest observable" temperature and a hottest-spot correction of 10°C added thereto.

178 In the case of resistance measurements, the temperature co-efficient of copper shall be deduced from the formula $1/(234.5 + t)$. Thus, at an initial temperature $t = 40°$ C. the temperature co-efficient or increase in resistance per degree centigrade rise is $1/(274.5) = 0.00364$. The following table, deduced from the formula, is given for convenience of reference.

*Whenever a sufficient time has elapsed between the instant of shut-down and the time of the final temperature measurement to permit the temperature to fall, suitable corrections shall be applied, so as to obtain as nearly as practicable the temperature at the instant of shut-down. This can sometimes be approximately effected by plotting a curve, with temperature readings as ordinates and time as abscissas, and extrapolating back to the instant of shut-down. In other instances, acceptable correction factors can be applied.

In cases where successive measurements show *increasing* temperatures after shut-down, the highest value shall be taken.

†As one of the few instances in which the thermometer check cannot be applied in Method No. 2, the rotor of a turbo-alternator may be cited.

Temperature of the winding, in degrees C. at which the initial resistance is measured.	Increase in resistance of copper per °C. per ohm of initial resistance
0	0.00 427
5	0.00 418
10	0.00 409
15	0.00 401
20	0.00 393
25	0.00 385
30	0.00 378
35	0.00 371
40	0.00 364

179 **In Coils of Low Resistance,** where the joints and connections form a considerable part of the total resistance, the measurement of temperature by the resistance method shall not be used.

180 **The Temperature of the Windings of Transformers** is always to be ascertained by Method 2. In the case of air-blast transformers, it is especially important to place thermometers near the air outlet.

182* **Method No. 3. Imbedded Temperature-Detector Method.**

Thermocouples or resistance coils, located as nearly as possible at the estimated hottest spot. This method is only to be used with coils placed in slots.

183 **By Building into the Machine** suitably placed thermocouples or resistance coils, a temperature not much less than that of the hottest spot will be disclosed. When these devices are adopted for such temperature determinations, a liberal number shall be employed, and and all reasonable efforts consistent with safety shall be made to locate them at the various places where the highest temperatures are likely to occur.

184 **Temperature-Detectors** should be placed in at least two sets of locations. One of these should be between coil and core, and one between the top and bottom coils, where two coils per slot are used. Where only one coil per slot is used, one set of detectors shall be placed between coil and core, and one set between coil and wedge.

185 Method No. 3 should be applied to all stators of machines with wide cores (50 cm.—20 in.—and over). It should also be applied to all machines of 5000 volts and over, if of over 500 kv-a., regardless of core width.

186 **Correction Factor for Method No. 3.**—In the case of two-layer windings with detectors between coils, and between coil and slot, add

181 Omitted.

5° C to the highest reading. In single-layer windings with detectors between coil and core and between coil and wedge, add to the highest reading 10° C. plus 1° C. per 1000 volts above 5000 volts of terminal pressure.

TEMPERATURE LIMITS

187 The following table gives the limits for the hottest-spot temperatures of insulations. The permissible limits are indicated in column 1 of the table. The limits of temperature rise permitted under rated-load conditions are given in column 2, and are found by subtracting 40° C. from the figures in column 1. Whatever be the ambient temperature at the time of the test, the rise of temperature observed must never exceed the limits in column 2 of the table. The highest temperatures attained in any machine corresponding to the output for which it is rated must not exceed the values indicated in column 1 of the table and clauses following.

188 **Table of Hottest-Spot Temperatures and of Corresponding Permissible Temperature Rises.**

Class	Description of Insulation	Column 1 Highest permissible temperatures for hottest spot	Column 2 Highest permissible temperature rise of hottest spot above 40° for the purpose of fixing the Institute Rating.
A1	Cotton, silk, paper and other fibrous materials, not so treated as to increase the thermal limit.	95°C	55°C
A2	Similar to A1, but treated or impregnated and including enameled wire.	105°C	65°C
B	Mica, asbestos or other material capable of resisting high temperatures, in which any Class A material or binder, if used, is for structural purposes only, and may be destroyed without impairing the insulating or mechanical qualities.	125°C	85°C
C	Fireproof and refractory materials.	See §190	

189 NOTE. The Institute recognizes the ability of manufacturers to employ Class B insulation successfully at maximum temperatures of 150° C. and even higher. However, as sufficient data covering experience over a period of years at such temperatures is at present unavailable, the Institute adopts 125° C as a conservative limit for this class of insulation, and any increase above this figure should be the subject of special guarantee by the manufacturer.

190 Class C. For fireproof and refractory materials such as pure mica, porcelain, etc., no limit is specified.

191 When a lower-temperature class material is comprised in a completed product to such an extent, or in such ways, that its subjection

to the temperature limits allowed for the higher-temperature class material, with which it is associated, would affect the integrity of the insulation either mechanically or electrically, the permissible temperature shall be fixed at such a value as shall afford ample assurance that no part of the lower-temperature class material shall be subjected to temperatures higher than those approved by the Institute and set forth above. See also **§150**.

192 **Table Summarizing the Temperature Conditions under the Three Preceding Methods of Measurement for Insulations of Classes A_1, A_2 and B.** (See next page)

SPECIAL CASES OF TEMPERATURE LIMITS

193 **Temperature of Oil.** The oil in which apparatus is immersed shall in no part have an observable temperature in excess of 90°C.

194 **Water-Cooled Transformers.** In these the hottest-spot temperature shall not exceed 85°C.

195 **Railway Motor Temperature Limits,** see **§419.**

196 **Squirrel-Cage and Amortisseur Windings.** In many cases the insulation of such windings is largely for the purpose of making the conductors fit tightly in their slots, and the slightest effective insulation is ample. In other cases, there is practically no insulating material on the windings. Consequently, the temperature rise may be of any value such as will not occasion mechanical injury to the machine.

197 **Collector Rings.** The temperature of collector rings shall not be permitted to exceed the "hottest-spot" values set forth in **§188** for the insulations employed either in the collector rings themselves, or in adjacent insulations whose temperatures would be affected by the heat from the collector rings. It has been suggested that the temperature of the rings shall in no case exceed 130°C.

198 **Commutators.** The observable temperature shall in no case be permitted to exceed the values given in **§188** for the insulation employed, either in the commutator or in any insulation whose temperature would be affected by the heat of the commutator.

For commutators so constructed that no difficulties from expansion can occur, the following temperature limits have been suggested:

Current per Brush Arm	Maximum Permissible Temp.
200 amperes or less	130°C.
200 to 900 amperes	130°C. less 5 deg. for each 100 amperes increase above 200.
900 amperes and over	95°C.

199 **Cores.** The temperature of those parts of the iron core in contact with insulating materials must not exceed the limits of temperature and temperature rise permitted for those materials.

200 **Other parts,** (such as brush-holders, brushes, bearings, pole-tips, cores, etc.) All parts of electrical machinery other than those

Table Referring to Section 192.

		METHOD I THERMOMETER ONLY			METHOD II RESISTANCE (With thermometer check when practicable)			METHOD III IMBEDDED THERMOCOUPLES OR RESISTANCE COILS								
								Double-Layer windings For all voltages			Single-Layer windings 5000 volts or less			Single-Layer Windings above 5000 volts		
Class	Permissible Hottest Spot Temp.	Hottest Spot Correction	Limiting Observable Temp.	Limiting Observable Temp. Rise above 40°	Hottest Spot Correction	Limiting Observable Temp	Limiting Observable Temp. Rise above 40°	Hottest Spot Correction	Limiting Observable Temp.	Limiting Observable Temp. Rise above 40°	Hottest Spot Correction.	Limiting Observable Temp.	Limiting Observable Temp. Rise above 40°	Hottest Spot Correction	Limiting Observable Temperature	Limiting Observable Temp. Rise above 40°
A_1	95°	15	80	40	10	85	45	5	90	50	10	85	45	10 + (E-5)*	85 - (E-5)	45 - (E-5)
A_2	105°	15	90	50	10	95	55	5	100	60	10	95	55	10 + (E-5)	95 - (E-5)	55 - (E-5)
B	125°	15	110	70	10	115	75	5	120	80	10	115	75	10 + (E-5)	115 - (E-5)	75 - (E-5)

*In this formula *E* represents the rated pressure between terminals in kilovolts. Thus for a three-phase machine with single-layer winding, of 11 kilovolts between terminals the hottest-spot correction to be added to the maximum observable temperature will be 16°C.

whose temperature affects the temperature of the insulating material, may be operated at such temperatures as shall not be injurious in any respect. But no part of continuous-duty machinery subject to handling in operation, such as brush-rigging, shall have a temperature in excess of 100°C. for more than a very brief time.

ADDITIONAL REQUIREMENTS

201 **Short-Circuit Stresses.**

The Institute recognizes the self-destructibility, both mechanical and thermal, of certain sizes and types of machines, when subjected to severe short-circuits, and recommends that ample protection be provided in such cases, external to the machine if necessary.

202 **Over-Speeds.**

All types of rotating machines shall be so constructed that they will safely withstand an over-speed of 25 per cent, except in the case of steam turbines, which, when equipped with emergency governors, shall be constructed to withstand 20 per cent over-speed.

In the case of series motors, it is impracticable to specify percentage values for the guaranteed over-speed, on account of the varying service conditions.

Water-wheel generators shall be constructed for the maximum runaway speed which can be attained by the combined unit.

203 **Momentary Loads.**

Machines shall be required to carry momentary loads of 150 per cent of the amperes at rated load, and commutating machinery shall commutate successfully under this condition. Successful commutation is such that neither brushes nor commutator are injured by the test.

Machines for duty-cycle operation shall be rated according to their equivalent load, either on the short-time or continuous basis, but if intended for operation with widely fluctuating loads, shall commutate successfully under their specified operating conditions. See **§ 145, 146.**

204 **Stalling Torque of Motors**

Motors for continuous service shall, except when otherwise specified, be required to develop a running torque at least 175 per cent of that corresponding to the running torque at their rated load, without stalling.

Obviously, duty-cycle machines must carry their peak loads without stalling.

WAVE FORM

205 The **Sine Wave** shall be considered as standard except where deviation therefrom is inherent in the operation of the machine.

206 **The deviation of wave form** from the sinusoidal is determined by superposing upon the actual wave, (as determined by oscillograph), the equivalent sine wave of equal length, in such a manner as to give the least difference, and then dividing the maximum difference between corresponding ordinates by the maximum value of the equivalent sine wave. A maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

EFFICIENCY AND LOSSES

207 **Machine Efficiency** is the ratio of the power delivered by the machine to the power received by it.

208 **Plant Efficiency** is the ratio of the energy delivered from the plant to the energy received by it in the same period of time,* the period of time to be suitably chosen.

209 **Conventional Efficiency** of machinery is the ratio of the output to the sum of the output and the losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practicably indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency." Efficiencies based upon conventional losses shall be specifically stated to be conventional efficiencies.

210 **Efficiency Determination.** Input and output determination of efficiency may be made directly, measuring the output by brake, or equivalent, where applicable. Within the limits of practical application, the circulating power method, sometimes described as the Hopkinson or "loading back" method, may be used. In machines where none of these methods are practicable the conventional efficiency should be employed, especially in the case of large machines of high efficiency.

211 Values for the indeterminate losses may also be obtained by brake or other direct test, and used in estimating actual efficiencies of similar machines, by the separate-loss method.

212 **Normal Conditions.** The efficiency shall correspond to, or be corrected to, the normal conditions herein set forth, which shall be regarded as standard. These conditions include voltage, current, power-factor, frequency, wave-shape, speed, temperature, or such of them as may apply in each particular case.

213 **Measurement of Efficiency.** Electric power shall be measured at the terminals of the apparatus. In polyphase machines, sufficient measurements shall be made on all phases to avoid errors of unbalance.

214 **Point at Which Mechanical Power Shall be Measured.** Mechanical power delivered by machines, shall be measured at the pulley, gearing, or coupling, on the rotor shaft, thus excluding the loss of power in the belt or gear friction. See, however, an exception in **§415.**

215 **The Efficiency of Alternating-Current Apparatus** shall be measured when the current is in phase with the terminal voltage, unless otherwise specified, or unless a definite phase difference is inherent in the apparatus, as in induction machinery.

216 **Efficiency of Alternating-Current Apparatus in regard to Wave Shape.** In determining the efficiency of alternating-current apparatus, the sine wave is to be considered as standard, unless a different wave form is inherent in the operation of the apparatus. See **§205.**

*** An exception should be noted in the case of the efficiency of storage batteries.**

217 **Temperature of Reference for Efficiency Determinations.** The efficiency, at all loads, of all apparatus, shall be determined at, or corrected to, a reference temperature of 75°C.

218 **The losses in constant-potential machinery,** either of the stationary type, or of the constant-speed rotary type, are of two classes; namely, those which remain substantially constant at all loads, and those which vary with the load. The former include iron losses, windage and friction, also I^2R losses in any shunt windings. The latter include I^2R losses in series windings. The constant losses may be determined by measuring the power required to operate the machine at no load, deducting any series I^2R losses. The variable loss at any load may be computed from the measured resistance of the series windings and the given load current.

219 **Stray Load Losses.** The above simple method of determining the losses and hence the efficiency is only approximate, since the losses which are assumed to be constant do actually vary to some extent with the load, and also because the actual loss in the copper windings is sometimes appreciably greater than the calculated I^2R loss. The difference between the approximate losses as above determined and the actual losses is termed the "stray load losses"*. These latter are due to distortions in electric or magnetic fluxes from their no-load distributions or values, brought about by the load current. They are usually only approximately measurable or may be indeterminable.

220 **Table of Losses.** Losses in apparatus may be classified as follows:

Accurately Measurable or Determinable	*Approximately Measurable or Determinable*	*Indeterminable*
a. No-Load Core Losses including eddy-current losses in conductors at no-load	*c.* Brush Friction Loss	*h.* Iron Loss due to flux distortion.
b. Load I^2R in windings No-Load I^2R " "	*d.* Brush-Contact Loss	*i.* Eddy-Current losses in conductors due to transverse fluxes occasioned by the load currents.
	e. Losses due to windage and to bearing friction	*k.* Eddy-Current losses in conductors due to tooth saturation resulting from distortion of the main flux.
	f. Extra copper loss in transformer windings, due to stray fluxes caused by load currents	*l* Tooth-frequency losses due to flux distortion under load.
	g. Dielectric Losses.	*m.* Short-Circuit Loss of Commutation.

***In the Table of § 220, stray load losses include f, h, i, k, l and m; but do not include increased core losses due to increased excitation for compensating internal drop under load.**

221 **Evaluation of Losses.** The larger individual losses are either accurately or approximately determinable, but certain of the indeterminable losses reach values in various kinds of machinery which require that they should be taken into account.

Methods of measuring, approximating or allowing for these various losses are given below.

LOSSES TO BE TAKEN INTO ACCOUNT IN VARIOUS TYPES OF MACHINES

222 **Continuous-Current Commutating Motors and Generators.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R loss in windings. (" " " ")

Brush contact I^2R loss. (Approximately Meas. or Deter) Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush;—*i. e.*, 2 volts for total brush drop—for either carbon or graphite brushes. See **§232** and **429**.

Friction of bearings and windage (Approx. Meas. or Deter.)

Rheostat losses, when present (Acc. Meas. or Deter.)

Brush friction (Approx. Meas. or Deter.)

All indeterminable load losses, (including stray-load iron losses) which may be important, which vary with the design, and for which no satisfactory method of determination has been found, shall be included as zero per cent in estimating conventional efficiency.

223 **Synchronous Motors and Generators.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R loss in windings. " " " " based upon rated kw. and power factor.

Stray load-losses. (Indeterminable.) In approximating these losses, the method described in **§236** shall be employed.

Friction of bearings and windage. (Approx. Meas. or Deter.)

(Brush friction and brush-contact loss is negligible.)

Rheostat losses, when present, corresponding to rated kw. and power factor. (Acc. Meas. or Deter.)

224 **Induction Machines.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in windings. " " " "

Stray load-losses. (Indeterminable.) In approximating these losses, the method described in **§237** shall be employed.

Brush friction when collector rings are present. (Approx. Meas. or Deter.)

Brush contact loss. (Approximately Meas. or Deter.). Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush,—for either carbon or graphite brushes. See **§232.**

Friction of bearings and windage (Approx. Meas. or Deter.)

225 **Commutating A-C. Machines**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in windings. (" " " ")

Brush friction. (Approx. Meas. or Deter.)

Brush contact loss. (Approx. Meas. or Deter.) Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush,—for either carbon or graphite brushes. See **§232** and **429**.

Friction of bearings and windage. (Approx. Meas. or Deter.)

Short-Circuit loss of commutation. (Indeterminable.) Iron loss due to flux distortion. (Indeterminable.) Eddy-current losses due to fluxes varying with load and saturation. (Indeterminable.)	The Institute is not at this time prepared to make recommendations for approximating these losses.

226 **Synchronous Converters.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in windings, based on rated kw. and power factor. (Approx. Meas. or Deter.)

Brush friction. (Approx. Meas. or Deter.)

Brush contact loss. (Approx. Meas. or Deter.) Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush,—for either carbon or graphite brushes. See **§232**.

Short-circuit loss of commutation. (Indeterminable) Iron loss due to flux distortion when present. (Indeterminable). Eddy-current losses due to fluxes varying with load and saturation. (Indeterminable.)	These losses, while usually of low magnitude, are erratic, and the Institute is not at this time prepared to make recommendations for approximating them.

Friction of bearings and windage. (Approx. Meas. or Deter.)

For the booster type of synchronous converter, where the booster forms an integral part of the unit, its losses shall be included in the total converter losses in estimating the efficiency.

227 **Transformers.** No-load losses. These include the core loss and the I^2R loss due to the exciting current, (Acc. Meas. or Deter.) and the dielectric hysteresis loss in the insulation, (Approx. Meas. or Deter.)

Load losses. These include I^2R loss in windings, and eddy-current losses in windings and core, due to fluxes varying with load. (Approx. Meas. or Deter.) See **§240** for the method of approximating these losses.

DETERMINATION OR APPROXIMATION OF LOSSES IN ROTATING MACHINERY

228 **Bearing Friction and Windage** may be determined as follows. Drive the machine from an independent motor, the output of which shall be suitably determined. The machine under test shall have its brushes removed and shall not be excited. This output represents the bearing friction and windage of the machine under test.

In the case of engine-type generators, one-half the output of the driving motor shall be charged against the generator for windage. The remainder, considered as bearing friction, shall be debited to the prime mover.

229 **Brush Friction of Commutator and Collector Rings.** Follow the test of **§228,** taking an additional reading with the brushes in contact with the commutator or collector rings. The difference between the output obtained in the test in **§228** and this output shall be taken as the brush friction. Note: The surface of commutator and brushes should already be smooth and glazed from running when this test is made.

230 **No-Load Core Loss.** Follow the test in **§229** with an additional reading taken with the machine excited. The difference between the output value of **§229** and the output value of this reading shall be taken as the no-load core loss. This no-load core loss shall be taken with the machine so excited, as to produce rated terminal voltage.

231 **No-Load Core Loss at the Internal Voltage Corresponding to Rated Load.** This shall be taken as in **§230,** except that the machine shall be so excited as to produce at the terminals the voltage corresponding to the calculated internal voltage for the load and power factor under consideration. For synchronous machines, since no generally accepted method has been determined for obtaining the stator reactance, the internal voltage shall be determined by adding resistance drop to the terminal voltage.

232 **Brush Contact Loss** depends largely upon the material of which the brush is composed. As indicating the range of variation the following table will be of interest:

Grade of Brush	Volts drop across one brush-contact. (Average of positive and negative brushes)
Hard Carbon	1.1
Soft Carbon	0.9
Graphite	0.5 to 0.8
Metal-Graphite types	0.15 to 0.5 (The former for largest proportion of metal)

One volt drop per brush shall be considered as the Institute Standard drop corresponding to the I^2R brush-contact loss, for carbon and graphite brushes. Metal-graphite brushes shall be considered as special. See **§429.**

233 **Field-Rheostat Losses** which are normally present shall be included in the generator losses where there is a field rheostat in series with the field magnets of the generator, even when the machine is separately excited.

234 **Ventilating Blower.** When a blower is supplied as part of a machine set, the power required to drive it shall be charged against the complete unit; but not against the machine alone.

235 **Losses in Other Auxiliary Apparatus.** Auxiliary apparatus, such as a separate exciter for a generator or motor, shall have its losses charged against the plant of which the generator and exciter are a part, and not against the generator.

236 **Stray Load Losses in Synchronous Generators and Motors.** These include iron losses, and eddy-current losses in the copper due to fluxes varying with load and due to saturation.

Stray load-losses are to be determined by operating the machine on short circuit and at rated-load current. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss for polyphase generators and motors. These losses in single-phase machines are large; but the Institute is not yet prepared to give a method for measuring them.

237 **Stray Load-Losses in Induction Machines.**

These include eddy-current losses in the stator copper, and other eddy-current losses due to fluxes varying with the load. In windings consisting of relatively small conductors, these eddy-current losses are usually negligible.

With rotor removed and for a given stator current, measure the input through the stator at different frequencies. Plot a curve of loss against frequency. At low frequencies, the loss becomes constant, indicating the I^2R value. The difference between this I^2R value and the total loss at normal frequency shall be taken as the stray load-loss. This method is not accurate with induction motors in which the slots are entirely closed. In such machines these losses may be greater.

238 **Polyphase Induction Motor Rotor I^2R Loss.** This should be determined from the slip whenever the latter is accurately determinable, using the following equation:

$$\text{Rotor } I^2R \text{ loss} = \frac{\text{Output} \times \text{slip}}{1 - \text{slip}}$$

In large slip-ring motors, in which the slip cannot be directly measured by loading, the rotor I^2R loss shall be determined by direct resistance measurement; the rotor full-load current to be calculated by the following equation:

$$\text{Current per ring} = \frac{\text{watts output}}{\text{Rotor voltage at stand-still} \times \sqrt{3} \times K}$$

This equation applies to three-phase rotors. For rotors wound for two phase, use 2 instead of the $\sqrt{3}$. K may be taken as 0.95

for motors of 150 kw. or larger. The factor K usually decreases as the size of motor is reduced, but no specific value can be stated for smaller sizes.

DETERMINATION OR APPROXIMATION OF LOSSES IN TRANSFORMERS

239 **No-Load Losses.** These shall be measured with open secondary circuit at the rated frequency, and with an applied primary voltage giving the rated secondary voltage plus the IR drop which occurs in the secondary under rated-load conditions. These no-load losses include core losses, consisting of hysteresis and eddy-current losses in the core, as well as dielectric loss in insulation due to electrostatic flux, which latter loss increases rapidly with temperature, and the test should therefore preferably be made at the reference temperature of 75°C.

240 **Stray Load-Losses.** These shall be measured by applying a primary voltage sufficient to produce rated-load current in the primary and secondary windings, the latter being short circuited. The stray load-losses will then be equal to the input decreased by the measured I^2R losses in both windings, as computed from resistance measurements at actual temperature, and the rated current. It is ordinarily immaterial whether the high-voltage or low-voltage winding is used as the primary winding in this test.

241 **Volt-Ampere Ratio of Transformers.**

The volt-ampere ratio which should not be confused with real efficiency, is the ratio of the volt-ampere output to the volt-ampere input of a transformer, at any given power factor.

242 **Methods of Loading Transformers for Temperature Tests.**

Wherever practicable, transformers should be tested under conditions that will give losses approximating as nearly as possible to those obtained under normal or specified load conditions, maintained for such a time as is necessary for the temperature to reach a steady value. The maximum temperature rises measured during this test should be considered as the observable temperature rises for the given load.

An approved method of making these tests is the **"loading back"** method. The principal variations of this method are—

243 (a) **With duplicate single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of two, with both primary and secondary windings connected in parallel. Normal magnetizing voltage should then be applied and the required current circulated from an auxiliary source. One transformer can be held under normal voltage and current conditions while the other may be operating under slightly abnormal conditions.

244 (b) **With one three-phase transformer.**

One three-phase transformer may be tested in a manner similar to (a), provided the primary and secondary windings are each connected in delta for the test. Normal three-phase magnetizing volt-

age should be applied and the required current circulated from an auxiliary single-phase source.

245 (c) **With three single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of three, in a manner similar to (b) by connecting both primary and secondary windings in delta and applying normal three-phase magnetizing voltage and circulating the required current from an auxiliary single-phase source.

246 NOTE:— Among other methods that have a limited application and can be used only under special conditions may be mentioned—

(1) Applying dead load by means of some form of rheostat.

(2) Running alternately for certain short intervals of time on open circuit and then on short circuit, alternating in this way until the transformer reaches steady temperature.

In this test the voltage for the open-circuit interval and the current for the short-circuit interval shall be such as to give the same integrated core loss, and the same integrated copper loss, as in normal operation.

DIELECTRIC TESTS OF MACHINERY

247 **Basis for Determining Test Voltages.** The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the machinery, and its normal operating voltage, upon the nature of the service in which it is to be used, and upon the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended, have been determined as reasonable and proper for the great majority of cases and are proposed for general adoption, except when specific reasons make a modification desirable.

248 **Condition of Machinery to be Tested.** Commercial tests shall, in general, be made with the completely assembled machinery and not with individual parts. The machinery shall be in good condition, and high-voltage tests, unless otherwise specified, shall be applied before the machine is put into commercial service. and shall not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests shall be made at the temperature assumed under normal operation. High-voltage tests to determine whether specifications are fulfilled, are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine shall be understood as being made at the factory.

249 **Points of Application of Voltage.** The test voltage shall be successively applied between each electric circuit and all other electric circuits and metal parts grounded.

250 **Interconnected Polyphase Windings** are c nsidered as one circuit. All windings of a machine except that under test, shall be connected to ground.

251 **Frequency, Wave Form and Test Voltage.** The frequency of the testing circuit shall not be less than the rated frequency of the apparatus tested. A sine-wave form is recommended. See **§205.** The test shall be made with alternating voltage having a crest value equal to $\sqrt{2}$ times the specified test voltage. In d.c. machines, and in the general commercial application of a.c. machines, the testing frequency of 60 cycles per second is recommended.

252 **Duration of Application of Test Voltage.** The testing voltage for all classes of apparatus shall be applied continuously for a period of 60 seconds.

253 **Apparatus for Use on Single-Phase, 3-Phase-Delta or 3-Phase-Star Circuits.** Apparatus, such as transformers, which may be used in star connection on three-phase circuits, shall have the delta voltage of the circuits on which they may be used indicated on the rating plate and the test shall be based on such delta voltage.

VALUES OF A-C. TEST VOLTAGES

254 **The Standard Test for All Classes of Appa atus, Except as Otherwise Specified, Shall be Twice the Normal Voltage of the Circuit to Which the Apparatus is Connected, Plus 1000 Volts.**

255 *Exception*—**Alternating-Current Apparatus connected to Permanently Grounded Single-Phase Systems, for use on Permanently Grounded Circuits of more than 300 Volts** shall be tested with 2.73 times the voltage of the circuit to ground + 1000 volts. This does not refer to three-phase apparatus with grounded star neutral.

256 *Exception*—**Distributing Transformers.** Transformers for primary pressures from 550 to 5000 volts, the secondaries of which are directly connected to consumers' circuits and commonly known as distributing transformers, shall be tested with 10,000 volts from primary to core and secondary combined. The secondary windings shall be tested with twice their normal voltage plus 1000 volts.

257 *Exception*—**Auto-Transformers** used for starting purposes, shall be tested with the same voltage as the test voltage of the apparatus to which they are connected.

258 *Exception*—**Household Devices.** Apparatus taking not over †660 watts and intended solely for operation on supply circuits not exceeding 250 volts, shall be tested with 900 volts.

259 *Exception*—**Apparatus for use on Circuits of 25 Volts or Lower,** such as bell-ringing apparatus,* electrical apparatus used in automobiles, apparatus used on low-voltage battery circuits, etc., shall be tested with 500 volts.

260 *Exception*—**Field Windings of Alternating-Current Generators** shall be tested with 10 times the exciter voltage, but in no case with less than 1500 volts

261 *Exception*—**Field Windings of Synchronous Machines,** including motors and converters requiring to be started from alternating-

†The present National Electric Code power limit for a single outlet.
*This rule does not include bell-ringing transformers of ratio 125 to 6 volts. See National Electric Code.

current circuits, shall be tested with **5000** volts, when the field is wound for 125 volts, and with **8000** volts when the field is wound for 250 volts or over. In no case shall the test voltage be lower than that given in **§260.**)

262 *Exception*—**Phase-Wound Rotors of Induction Motors required to reverse in service.**

In order to allow for the extra voltage caused by the increased frequency at the instant of reversal, this test shall be four times stand-still voltage, plus 1000.

263 *Exception*—**Switches and Circuit Control Apparatus** above **600** volts, shall be tested with 2½ times rated voltage, plus **2000** volts. See **§367** to **387.**

264 *Exception*—**Assembled Apparatus.** Where a number of pieces of apparatus are assembled together and tested as an electrical unit, they shall be tested with 15 per cent lower voltage than the lowest required on any of the individual pieces of apparatus.

265 **Testing Transformers by Induced Voltage.** Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings, in place of using a separate testing transformer. By "required voltage" is meant, a voltage such that the line end of the windings shall receive a test to ground equal to that required by the general rules.

266 **Transformers with Graded Insulation** shall be so marked. They shall be tested by inducing the required test-voltage in the transformer and connecting the successive line leads to ground.

MEASUREMENT OF VOLTAGE IN DIELECTRIC TESTS OF MACHINERY

267 **Use of Voltmeters and Spark-Gaps in Insulation Tests.** When making insulation tests on electrical machinery, every precaution must be taken against the occurrence of any spark-gap discharges in the circuits from which the machinery is being tested. A non-inductive resistance of about one ohm per volt shall be inserted in series with one terminal of the spark gap. If the test is made with one electrode grounded, this resistance shall be inserted directly in series with the non-grounded electrode. If neither terminal is grounded, one-half shall be inserted directly in series with each electrode. In any case this resistance shall be as near the measuring gap as possible and not in series with the tested apparatus. The resistance will damp high-frequency oscillations at the time of breakdown and limit the current which will flow. A water tube is the most reliable form of resistor. Carbon resistors should not be used because their resistance becomes very low at high voltages.

268 For Machinery of Low Capacitance. When the machinery under test does not require sufficient charging current to distort the high-voltage wave shape, or change the ratio of transfor-

mation, the spark gap should be set for the required test voltage and the testing apparatus adjusted to give a voltage at which this spark gap just breaks down. This adjustment should be made with the apparatus under test disconnected. The apparatus should then be connected, and with the spark gap about 20 per cent longer, the testing apparatus is again adjusted to give the voltage of the former breakdown, which is the assumed voltage of test. This voltage is to be maintained for the required interval.

269 FOR MACHINERY OF HIGH CAPACITANCE. When the charging current of the machinery under test may appreciably distort the voltage wave or change the effective ratio of the testing transformer in the first adjustment of voltage with the gap set for the test voltage should be made with the apparatus under test connected to the circuit and in parallel with the spark gap.

When making arc over tests of large insulators, leads, etc. partial arc-over of the tested apparatus may produce oscillations which will cause the measuring gap to discharge prematurely. The measured voltage will then appear too high. In such tests the " equivalent " ratio " of the testing transformer should be measured by gap to within 20% of the arc-over voltage of the tested apparatus with the tested apparatus in circuit. The measuring gap should then be greatly lengthened out and the voltage increased until the tested apparatus arcs over. This arc-over voltage should then be determined by multiplying the voltmeter reading by the equivalent ratio found above. Direct measurement of the spark-over voltage over one gap by another gap should always be avoided.

270 **Measurements with Voltmeter.** In measuring the voltage with a voltmeter, the instrument should preferably derive its voltage from the high-tension circuit, either directly as with an electrostatic voltmeter, by means of a voltmeter coil placed in the testing transformer; or through an auxiliary *ratio transformer.* It is permissible to measure the voltage at other places, such as the transformer primary, provided corrections can be made for the variations in ratio caused by the charging current of the machinery under test, or provided there is no material variation of this ratio. In any case, when the apparatus to be tested in sufficiently large in relation to the testing apparatus to cause wave distortion, the voltage must be checked by spark gap, as set forth in **§275.**

271 **Measurements with Spark Gaps.** If proper precautions are observed, spark gaps may be used to advantage in checking the calibration of voltmeters when set up for the purposes of high-voltage tests of the insulation of machinery.

272 **Ranges of Voltages.** For such Calibrating Purposes:

THE NEEDLE SPARK-GAP should preferably be used for voltages from 10 kv. to 50 kv. because of the larger air gaps involved.

A SPHERE SPARK GAP should be used above 50 kv.

273 **The Needle Spark Gap.** The needle spark gap shall consist of new sewing needles supported axially at the ends of linear conductors

which are at least twice the length of the gap. There must be a clear space around the gap for a radius of at least twice the gap length.

274 **Sparking Distance.** The sparking distances in air between needle points for various root-mean-square sinusoidal voltages in mm. are as follows:

NEEDLE-POINT SPARK-OVER VOLTAGES WITH NO. 00 SEWING NEEDLES

(At 25°C and 760 mm. barometer).

R.M.S. Kilovolts	Millimeters	R.M.S. Kilovolts	Millimeters
10	11.9	40	62
15	18.4	45	75
20	25.4	50	90
25	33	60	118
30	41	70	149
35	51	80	180

The above values refer to a relative humidity of 80 per cent. Variations from this humidity may involve appreciable variations in the sparking distance.

275 **The Sphere Spark-Gap.** The standard sphere spark-gap shall consist of two suitably mounted metal spheres.

No extraneous body or external part of the circuit shall be near the gap within twice the diameter of the spheres. By the "gap" is meant the shortest path between the two spheres.

The shanks should not be greater in diameter than 1/5th the sphere diameter. Metal collars, etc. through which the shanks extend, should be as small as practicable and should not during any measurement come closer to the sphere than the maximum gap length used in that measurement.

The sphere diameter should not vary more than 0.1 per cent and the curvature, measured by a spherometer, should not vary more than 1 per cent from that of a true sphere of the required diameter.

All gaps are affected by barometric pressure and temperature. and if tests are not made at 25°C and 760 millimeters barometric, pressure, appropriate corrections must be applied. The Institute is not at present prepared to make recommendations as to the amount of such corrections.

276 The sparking distances between different spheres for various r.m.s. sinusoidal voltages shall be assumed to be as follows:

SPHERE GAP SPARK-OVER VOLTAGES

(At 25°C and 760 mm. barometric pressure)

Kilovolts	Sparking Distance in Millimeters.					
	125 mm. spheres		250 mm. spheres		500 mm. spheres	
	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insulated
30	14.1	14.1				
40	19.1	19.1				
50	24.4	24.4				
60	30	30	29	29		
70	36	36	35	35		
80	42	42	41	41	41	41
90	49	49	46	45	46	45
100	56	55	52	51	52	51
120		71	64	63	63	62
140		88	78	77	74	73
160		110	92	90	85	83
180			109	106	97	95
200			128	123	108	106
220			150	141	120	117
240			177	160	133	130
260					148	144
280					163	158
300					177	171
320					194	187
340					214	204
360					234	221

The sphere gap is more sensitive than the needle gap to momentary rises of voltage and the voltage required to spark over the gap should be obtained by slowly closing the gap under constant voltage, or by slowly raising the voltage with a fixed setting of the gap.

INSULATION RESISTANCE OF MACHINERY

277 **The insulation resistance of a machine** at its operating temperature shall be not less than that given by the following formula:

Insulation Resistance in megohms =

$$\frac{\text{voltage at terminals}}{\text{rated capacity in kv-a.} + 1000}$$

The formula only applies to dry apparatus. Such high values are not attainable in oil-immersed apparatus.

Insulation resistance tests shall, if possible, be made at a d.c. pressure of 500 volts. Since the insulation resistance varies with the pressure, it is necessary that, if a pressure other than 500 volts is to be employed in any case, this other pressure shall be clearly specified.

The order of magnitude of the values obtained by this rule is shown in the following table:

Rated Voltage of machine	Megohms		
	100 kv-a.	1000 kv-a.	10,000 kv-a.
100	0.091	0.05	—
1,000	0.91	0.50	0.091
10,000	9.1	5.0	0.91
100,000	—	50	9.1

278 It should be noted that the insulation resistance of machinery is of doubtful significance by comparison with the dielectric strength. The insulation resistance is subject to wide variation with temperature humidity and cleanliness of the parts. When the insulation resistance falls below that corresponding to the above rule, it can in most cases of good design, and where no defect exists, be brought up to the required standard by cleaning and drying out the machine. The insulation resistance test may therefore afford a useful indication as to whether the machine is in suitable condition for the application of the dielectric test.

REGULATION

DEFINITIONS

279 **Regulation.** The regulation of a machine in regard to some characteristic quantity (such as terminal voltage or speed) is the change in that quantity occurring between any two loads. Unless otherwise specified, the two loads considered shall be zero load and rated load and at the temperature attained under normal operation. The regulation may be expressed by stating the numerical values of the quantity at the two loads, or it may be expressed by the " percentage regulation " which is the percentage ratio of the change in the quantity occurring between the two loads to the value of the quantity at either one or the other load, taken as the normal value. It is assumed that all parts of the machine affecting the regulation maintain constant temperature between the two loads, and where the influence of temperature is of consequence, a reference temperature of 75°C shall be considered as standard. If change of temperature should occur during the tests the results shall be corrected to the reference temperature of 75°C.

The normal value may be either the no-load value, as the no-load speed of induction motors; or it may be the rated-load value as in the voltage of a.c. generators.

It is usual to state the regulation of d-c. generators by giving the numerical values of the voltage at no load and rated-load, and in some cases it is advisable to state regulation at intermediate loads.

280 The **Regulation of d-c. Generators** refers to changes in voltage corresponding to gradual changes in load and does not relate to the comparatively large momentary fluctuations in voltage that frequently accompany instantaneous changes in load.

In determining the regulation of a compound-wound d-c. gener-

ator, two tests shall be made, one bringing the load down and the other bringing the load up between no-load and rated load. These may differ somewhat, owing to residual magnetism. The mean of the two results shall be used.

281 In **constant-potential a-c. generators,** the regulation is the **rise** in voltage (when the specified load at specified power factor **is** thrown off) expressed in per cent of normal rated-load voltage.

282 In **constant-current machines,** the regulation is the ratio of the maximum difference of current from the rated-load value (occurring in the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

283 In **constant-speed direct-current motors,** and induction motors, the regulation is the ratio of the difference between full-load and no-load speeds to the no-load speed.

284 In **constant-potential transformers** the regulation is the difference between the no-load and rated-load values of the secondary terminal voltage, at the specified power factor (with constant primary impressed terminal voltage) expressed in per cent of the rated-load secondary voltage, the primary voltage being adjusted to such a value that the apparatus delivers rated output at rated secondary voltage.

285 In **converters, dynamotors, motor-generators and frequency converters,** the regulation is the change in the terminal voltage of the output side between the two specified loads. This may be expressed by giving the numerical values or as the percentage ratio.

286 In **transmission lines, feeders etc.,** the regulation is the change in the voltage at the receiving end between rated non-inductive load and no load, with constant impressed voltage upon the sending end. The percentage regulation is the percentage change in voltage to the normal rated voltage at the receiving end.

287 In **steam engines, steam turbines and internal combustion engines,** the percentage speed regulation is usually expressed as the percentage ratio of the maximum variation of speed to the rated-load speed in passing slowly from rated load to no load (with constant conditions at the supply.)

288 If the test is made by passing suddenly from rated load to no load, the immediate percentage speed regulation so derived shall be termed the **fluctuation.**

289 In **a hydraulic turbine,** or other water motor, the percentage speed regulation is expressed as the percentage ratio of the maximum variation in speed in passing slowly from rated load to no load (at constant head of water), to the rated-load speed.

290 In **a generator unit** consisting of a generator combined with a prime mover, the speed or voltage regulation should be determined at constant conditions of the prime mover, *i.e.* constant steam-pressure, head, etc. It includes the inherent speed variations of the prime mover. For this reason, the regulation of a generator unit is to be distinguished from the regulation of either the prime mover, or of the generator combined with it, when taken separately.

CONDITIONS FOR TESTS OF REGULATION

291 **Speed and Frequency.** The regulation of generators is to be determined at constant speed, and of alternating-current apparatus at constant frequency.

292 **Power Factor.** In apparatus generating, transforming or transmitting alternating currents, the power factor of the load to which the regulation refers should be specified. Unless otherwise specified, it shall be understood as referring to non-inductive load, that is to a load in which the current is in phase with the *e.m f.* at the output side of the apparatus.

293 **Wave Form.** In the regulation of alternating-current machinery receiving electric power, a sine wave of voltage is assumed, except where expressly specified otherwise. See **§205.**

294 **Excitation.** In commutating machines, rectifying machines, and synchronous machines, such as direct-current generators and motors, as well as in alternating-current generators, the regulation is to be determined under the following conditions, so as to maintain the field adjustment constant at that which gives rated-load voltage at rated-load current.

(1) In the case of separately excited field magnets—constant excitation.

(2) In the case of shunt machines, constant resistance in the shunt-field circuit.

(3) In the case of series or compound machines, constant resistance shunting the series-field windings.

295 **Tests and Computation of Regulation of A-C. Generators.**

Any one of the three following methods may be used. They are given in the order of preference.

Method a.

The regulation can be measured directly by loading the generator at the specified load and power factor, then reducing the load to zero, and measuring the terminal voltage, with speed and excitation adjusted to the same values as before the change. This method is not generally applicable for shop tests, particularly on large generators, and it becomes necessary to determine the regulation from such other tests as can be readily made.

296 **Method b.**

This consists in computing the regulation from experimental data of the open-circuit saturation curve and the zero-power factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by running the generator with over-excited field on a load of idle-running under-excited synchronous motors. The power factor under these conditions is very low and the load saturation curve approximates very closely the zero power factor saturation curve. From this curve and the open circuit curve, points for the load saturation curve for any power factor can be obtained by means of vector diagrams.

To apply Method b, it is necessary to obtain from test, the open-circuit saturation curve *OA*, Fig. 1, and the saturation curve *BC* at

zero power factor and rated-load current. At any given excitation *Oc*, the voltage that would be induced on open circuit is *ac*, the terminal voltage at zero power factor is *bc*, and the apparent internal drop is *ab*. The terminal voltage *dc* at any other power factor can then be found by drawing an e.m.f. diagram* as in Fig. 2, where ϕ is

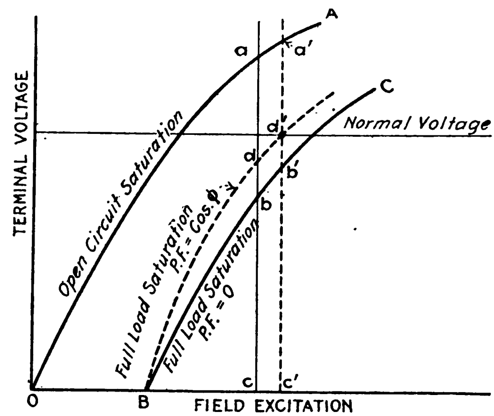


FIG. 1

an angle such that *cos* ϕ is the power factor of the load, *b e* the resistance drop (*IR*) in the stator winding, *ba* the total internal drop and *ac* the total induced voltage; *ba* and *ac* being laid off to correspond with the values obtained from Fig. 1. The terminal voltage at power

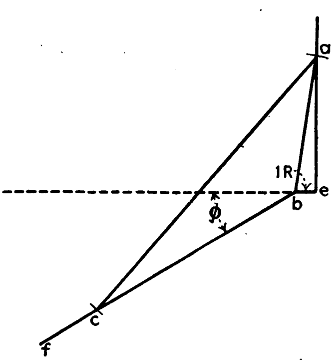


FIG. 2

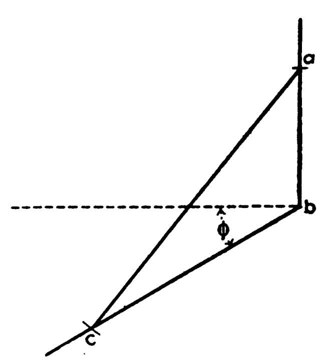


FIG. 3

factor *cos* ϕ is then *cb* of Fig. 2 which, laid off in Fig. 1, gives point *d*. By finding a number of such points, the curve *Bdd'* for power factor

***Method b, for deducing the load saturation curve, at any assigned power factor, from no-load and zero-power-factor saturation curves obtained by test, must be regarded as empirical. Its value depends upon the fact that experience has demonstrated the reasonable correctness of the results obtained by it.**

cos ϕ is obtained and the regulation at this power factor (expressed in per cent) is $\frac{100 \times a'd'}{d'c'}$, since a' d' is the rise in voltage when the load at power factor *cos* ϕ is thrown off at normal voltage c' d'.

Generally, the ohmic drop can be neglected, as it has very little influence on the regulation, except in very low-speed machines, where the armature resistance is relatively high, or in some cases where regulation at unity power factor is being estimated; for low power factors, its effect is negligible in practically all cases. If resistance is neglected, the simpler e.m.f. diagram, Fig. 3, may be used to obtain points on the load saturation curve for the power factor under consideration.

297 **Method c.**

Where it is not possible to obtain by test a zero power factor sat-

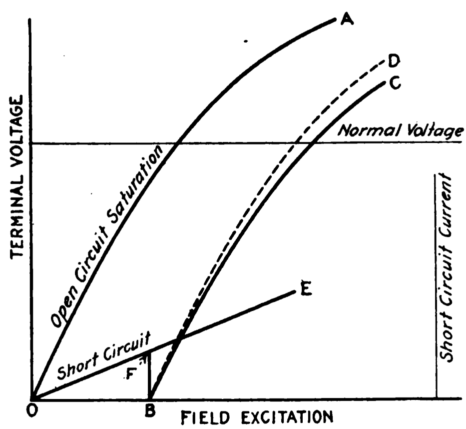


FIG. 4

uration curve as in method b, this curve can be estimated closely from open-circuit and short-circuit curves, by reference to tests at zero power factor on other machines of similar magnetic circuit. Having obtained the estimated zero power factor curve, the load saturation for any other power factor is obtained as in method b.

Thus method c is the same as method b; except that the zero power factor curve must be estimated. This may be done as follows. In Fig. 4, *OA* is the open-circuit saturation curve and *OE* the short-circuit line as shown by test. The zero power factor curve corresponding to any given current *BF* will start from point *B* and for machines designed with low saturation and low reactance, will follow parallel to *OA*, as shown by the dotted curve *BD*, which is *OA* shifted parallel to itself by the distance *OB*. In high speed machines, or in others having low reactance and a low degree of saturation in the magnetic circuit, the zero power factor curve will lie quite close to *BD*, particularly

in those parts that are used for determining the regulation. This is the case with many turbo-generators and high-speed water-wheel generators. In many cases, however, the zero power factor curve will deviate from BD, as shown by BC, and the deviation will be most pronounced in machines of high reactance, high saturation, and large magnetic leakage. The position of the actual curve BC with relation to BD can be approximated with sufficient exactness by investigating the corresponding relation as obtained by test at zero power factor on machines of similar characteristics and magnetic circuit. Or curve BC can be calculated by methods based on the results of tests at zero power factor. After BC has been obtained, the saturation curve and regulation for any other power factor can be derived as in Method (b).

298 **Tests and Computation of Regulation for Constant-Potential Transformers.**

The regulation can be determined by loading the transformer and measuring the change in voltage with change in load at the specified power factor. This method is not generally applicable for shop tests, particularly on large transformers.

The regulation for any specified load and power factor can be computed from the measured impedance watts and impedance volts as follows:

Let:

P = impedance watts as measured in the short-circuit test at 75°C.

E_z = impedance volts as measured in the short-circuit test.

IX = Reactance Drop in Volts.

I = Rated Primary Current.

E = Rated Primary Voltage.

q_r = percent drop in phase with current

q_x = percent drop in quadrature with current

$$IX = \sqrt{E_z^2 - \left(\frac{P}{I}\right)^2}$$

$$q_r = 100\frac{P}{EI}$$

$$q_x = 100\frac{IX}{E}$$

301* Then—

1. For **unity power factor**

$$\text{Per cent regulation} = q_r + \frac{q_x^2}{200}$$

*§§299 and 300 omitted.

302 2. For **inductive loads** of power-factor m and reactive-factor n,

$$\text{Per cent regulation} = mq_r + nq_x + \frac{(mq_x - nq_r)^2}{200}$$

TRANSFORMER CONNECTIONS

SINGLE-PHASE TRANSFORMER

303 **Marking of Leads.**

The leads of single-phase transformers shall be distinguished from each other by marking the high-voltage leads with the letters A and B, and the low-voltage leads with the letters X and Y. They shall be so marked that the potential difference between A and B shall have the same direction at any instant as the potential difference between X and Y.

In accordance with the above rule, the terminals of single-phase transformers shall be marked as follows:

304 (1) High- and Low-Voltage Windings in Phase:

$$\begin{array}{c} A \text{———} B \\ X \text{———} Y \end{array}$$

305 (2) High- and Low-Voltage Windings 180 deg. Apart in Phase:

$$\begin{array}{c} A \text{———} B \\ Y \text{———} X \end{array}$$

306 To operate transformers thus marked in parallel, it is only necessary to connect similarly marked terminals together, (provided that the reactances and resistances of the transformers are such as to permit of parallel operation).

307 **Single-Phase Transformers with More Than Two Windings.**

Transformers possessing three or more windings (each being provided with separate out-going leads), shall have the leads connected to two of their windings, lettered in accordance with the preceding paragraph. The remaining leads shall be distinguished from the others by a subscript. For example, transformers possessing four secondary leads connected to two distinct similar windings for multiple-series operation, shall be lettered as follows:

$$\begin{array}{c} A \text{———} B \\ \left\{\begin{array}{c} X \text{———} Y \\ X_1 \text{———} Y_1 \end{array}\right\} \end{array}$$

This indicates that the low-voltage winding consists of two disconnected parts, one part having terminals XY and the other part having terminals X_1Y_1. For multiple connection, X and X_1 are connected together and Y and Y_1 are connected together. For series connection, Y is connected to X_1.

308 **Neutral Lead**

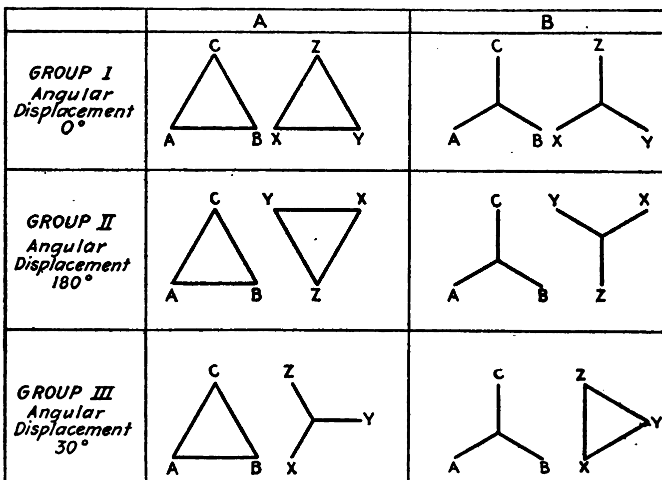
An out-going 50 per cent. (neutral) tap lead should be lettered N.

309 **Internal Connections**

The manufacturer shall furnish a complete diagrammatic sketch of internal connections, and all taps and terminals of the transformer shall be marked to correspond with numbers or letters in the sketch.

THREE-PHASE TRANSFORMERS

310 Three-phase transformers ordinarily have three or four leads for high-voltage, and three or four leads for low-voltage windings. To distinguish the various leads from each other, and also to distinguish between the various phase relations obtainable, the three high-voltage leads should be lettered A B C and the three low-voltage leads X Y Z. In addition, it should be distinctly stated in which of the three groups given in the accompanying diagram the transformer belongs.



The rules given above for single-phase transformers in regard to the neutral tap, (See §308) and also in regard to internal connections, (See §303 to §307) are applicable to three-phase transformers.

311 **Angular Displacement.**

The angular displacement between high- and low-voltage windings is the angle in the accompanying diagram, between the lines passing from the neutral point through A and X respectively. Thus, in Group 1, the angular displacement is zero degrees. In Group 2, the angular displacement is 180°, and in Group 3 the angular displacement is 30°.

312 **Parallel Operation of Three-Phase Transformers.**

Three-phase transformers, lettered in accordance with the above rules, will operate correctly in parallel, if at their rated loads, their percentage resistance drops are equal, and their percentage reactance drops, are equal. It is furthermore necessary that the angular displacements between high-voltage and low-voltage windings shall

be equal, *i.e.* that the transformers shall belong to the same group in the accompanying diagram. It is then only necessary to connect together similarly marked leads.

INFORMATION ON THE RATING PLATE OF A MACHINE

313 (a) It is recommended that the rating plate of machines which comply with the Institute rules shall carry a distinctive special sign, such as " A.I.E.E. 1914 Rating" or "A14" Rating.

(b) The absence of any statement to the contrary on the rating plate of a machine implies that it is intended for continuous service and for the standard altitude and ambient temperature of reference. See **§§148, 153, 156** and **157.**

(c) The rating plate of a machine intended to work under various kinds of rating must carry the necessary information in regard to those kinds of ratings.

(d) The rating plate, in addition to the name of the manufacturer and the serial number, should give the following information.*

314 **Generator, Direct-Current.**
Shunt, series, or compound.
Output, in kw., with statement as to the kind of rating.
Terminal pressure, in volts.
Current, in amperes.
Speed, in revolutions per minute.

315 **Motor, Direct-Current,**
Shunt, series, or compound.
Output, in kw., with statement as to the kind of rating.
Terminal pressure, in volts.
Current, approximate, in amperes.
Speed, in revolutions per minute.

316 **Transformer.**
Frequency, in cycles per second.
Number of phases.
Output at the secondary terminals in kv-a., with statement as to the kind of rating.
High pressure, in volts.
Low pressure, in volts. See **§§109, 110** and **111.**
Lead markings and diagram of internal connections as set forth in **§303** to **312.**

317 **Alternator.**
Frequency, in cycles per second.
Number of poles.
Number of phases.
Output, in kv-a., with statement as to the kind of rating power-factor corresponding to rated output.
Pressure between terminals, in volts, corresponding to the rated output.
Current in amperes.

***Information, for which space on the rating plate cannot be provided, shall be furnished on a supplementary rating certificate.**

Speed in revolutions per minute.

Excitation pressure, in volts.

Maximum exciting current, in amperes, required to maintain rated voltage under rated load.

318 **Synchronous Motor.**

Frequency, in cycles per second.

Number of poles.

Number of phases.

Mechanical output, in kw., with statement as to the kind of rating.

Pressure between terminals, in volts, corresponding to the rated output.

Current in amperes.

If the motor is intended to work with a power factor different from unity, the necessary information shall be given.

Speed, in revolutions per minute.

Excitation pressure, in volts.

Maximum exciting current, in amperes, required to maintain rated power factor at rated load.

319 **Synchronous Converter.**

Frequency in cycles per second.

Number of poles.

Shunt or compound.

Number of phases.

Output at commutator in kilowatts, with statement as to kind of rating. In case of a converter for railroad service, both nominal and continuous ratings.

A-c. terminal pressure in volts.

D-c. terminal pressure in volts.

Current from commutator in amperes.

Speed in revolutions per minute.

320 **Induction Motor.**

Frequency, in cycles per second.

Number of poles.

Number of phases.

Mechanical output, in kw., with statement as to the kind of rating.

Pressure between terminals, in volts.

Current, in amperes.

Speed, in revolutions per minute, at rated output.

Secondary pressure (initial) when starting.

STANDARDS FOR WIRES AND CABLES

TERMINOLOGY*

321 **Wire.**—A slender rod or filament of drawn metal.

The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense, that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire. While primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated the term "wire" will be understood to include the insulation.

322 **Conductor.**—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current.

The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents.

Rolled conductors (such as busbars) are, of course, conductors, but are not considered under the terminology here given.

323 **Stranded Conductor.**—A conductor composed of a group of wires or of any combination of groups of wires.

The wires in a stranded conductor are usually twisted or braided together.

324 **Cable.**—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several conductors. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead-covered. This usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one and in practise it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead, or with steel wires or bands.

325 **Strand.**—One of the wires or groups of wires of any stranded conductor.

326 **Stranded Wire.**—A group of small wires, used as a single wire.

A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called a "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.

327 **Cord.**—A small and very flexible cable, substantially insulated to withstand wear.

There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Rubber is used as the insulating material for many classes of cords.

328 **Concentric Strand.**—A strand composed of a central core

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*From Circular No. 37 of the Bureau of Standards.

surrounded by one or more layers of helically-laid wires or groups of wires.

329 **Concentric-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid wires.

330 **Rope-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid groups of wires.

This kind of cable differs from the preceding in that the main strands are themselves stranded.

331 **N-Conductor Cable.**—A combination of N conductors insulated from one another.

It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable" etc. In referring to the general case, one may speak of a "multiple-conductor cable" (as in definition §324 above.)

332 **N-Conductor Concentric Cable.**—A cable composed of an insulated central conducting core with (N — 1) tubular stranded conductors laid over it concentrically and separated by layers of insulation.

This kind of cable usually has only 2-conductor or 3-conductor. Such cables are used in carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.

333 **Duplex Cable.**—Two insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

334 **Twin Cable.**—Two insulated single-conductor cables laid parallel, having a common covering.

335 **Triplex Cable.**—Three insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

336 **Twisted Pair.**—Two small insulated conductors twisted together, without a common covering.

The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

337 **Twin Wire.**—Two small insulated conductors laid parallel, having a common covering.

338 **Specification of Sizes of Conductors.** The sizes of solid wires shall be stated by their diameter in mils, the American Wire Gage (Brown and Sharpe) sizes being taken as standard. The sizes of stranded conductors shall be stated by their cross-sectional area in circular mils. For brevity, in cases where the most careful specification is not required, the sizes of solid wires may be stated by the gage number in the American Wire Gage, and the sizes of stranded conductors smaller than 250,000 circular mils (*i.e.*, No. 0000 A.W.G. or smaller) may likewise be stated by means of the gage number in the American Wire Gage of a solid wire having the same cross-sectional area. Futhermore, an exception is made in the case of "Flexible Stranded Conductors," for which see **§341** below. In **stating large cross-sections,** it is sometimes convenient to use a circular inch (507 sq. mm.) instead of 1,000,000 circular mils.

STRANDING

339 The Standard Concentric Stranding Table printed in Circulars 31 and 37 of the Bureau of Standards, is adopted.

Standardization of Concentric Stranding.

Range of Sizes.		Number of Wires. Standard Concentric-lay Cables.
Circular mils.	Sq. mm.	
2,000,000 to 1,600,000....	1015 to 810	127
1,500,000 to 1,100,000....	760 to 560	91
1,000,000 to 550,000....	507 to 280	61
500,000 to 250,000....	253 to 127	37
No. 0000 to No. 1 A.W.G.	107 to 42	19
No. 2 and smaller.......	34 and smaller	7

340 **Sectional Area of Cables.** The cross-sectional area of a cable shall be considered to be the sum of the cross-sectional areas of its component wires, when laid-out straight and measured perpendicular to their axes.

341 **Flexible Stranding.** Conductors of special flexibility should ordinarily be made with wires of regular A.W.G. sizes, the number of wires and size being given. The approximate gage number or approximate circular mils of such flexible stranded conductors may be stated.

342 **Correction for Lay.** The resistance and mass of a stranded conductor are greater than in a solid conductor of the same cross-sectional area, depending on the lay (*i.e.*, the pitch of the twist of the wires). Two per cent shall be taken as the standard increment of resistance and of mass. In cases where the lay is definitely known, the increment should be calculated and not assumed.

The direction of lay is the lateral direction in which the strands of a cable run over the top of the cable as they recede from an observer looking along the axis of the cable.

CONDUCTIVITY OF COPPER.

343 The following I. E. C. rules are adopted:*

The following shall be taken as normal values for standard annealed copper:

(1) At a temperature of 20 °C. the resistance of a wire of standard annealed copper one meter in length and of a uniform section of 1 square millimeter is 1/58 ohm = 0.017241....ohm.

(2) At a temperature of 20 °C. the density of standard annealed copper is 8.89 grams per cubic centimeter.

(3) At a temperature of 20 °C. the "constant mass" temperature coefficient of resistance of standard annealed copper, measured between two potential points rigidly fixed to the wire, is 0.00393 = 1/254.45....per degree centigrade.

(4) As a consequence, it follows from (1) and (2) that, at a temperature of 20 °C. the resistance of a wire of standard annealed

*See I. E. C. Publication No. 28 "International Standard of Resistance for Copper" March 1914.

copper of uniform section, one meter in length and weighing one gram, is (1/58) × 8.89 = 0.15328......ohm.†§

344 **Copper Wire Tables.** The copper-wire Tables published by the Bureau of Standards in Circular No. 31 are adopted. These Tables are based upon the I. E. C. rules stated in **§343.**

HEATING AND TEMPERATURE OF CABLES.

345 **Maximum Safe Limiting Temperatures.**

The maximum safe limiting temperature in degrees C. at the surface of the conductor in a cable shall be:—

For impregnated paper insulation	(85—E)
" varnished cambric	(75—E)
" rubber insulation	(60—0.25E)

where E represents the r.m.s. operating e.m.f. in kilovolts between conductors.

Thus, at a working pressure of 3.3 kv., the maximum safe limiting temperature at the surface of the conductor or conductors in a cable would be:—

For impregnated paper	81.7°C.
" varnished cambric	71.7°C.
" rubber insulation	59.2°C.

ELECTRICAL TESTS.

346 **Lengths Tested.** Electrical tests of insulation on wires and cables shall be made on the entire lengths to be shipped.

347 **Immersion in Water.** Electrical tests of insulated conductors not enclosed in a lead sheath shall be made while immersed in water after an immersion of twelve (12) hours, if insulated with rubber compound, or if insulated with varnished cambric. It is not necessary to immerse in water insulated conductors enclosed in a lead sheath.

In multiple-conductor cables, without waterproof overall jacket of insulation, no immersion test should be made on finished cables, but only on the individual conductors before assembling.

348 **Dielectric-Strength Tests. Object of Tests.** Dielectric tests are intended to detect weak spots in the insulation and to determine whether the dielectric strength of the insulation is sufficient for enabling it to withstand the voltage to which it is likely to be subjected in service, with a suitable factor of assurance.

The initially applied voltage must not be greater than the working voltage, and the rate of increase shall not be over 100 per cent in 10 seconds.

349 **Factor of Assurance.** The factor of assurance of wire or cable insulation shall be the ratio of the voltage at which it is tested to that at which it is used.

†Paragraphs (1) and (4) of §343 define what are sometimes called "volume resistivity," and "mass resistivity" respectively. This may be expressed in other units as follows:— volume resistivity = 1.7241 microhm-cm. (or microhms in a cm. cube) at 20 deg. cent. = 0.67879 microhm-inch at 20 deg. cent., and mass resistivity = 875.20 ohms (mile, pound) at 20 deg. cent.

§For detailed specifications of commercial copper, see the "Standard Specifications" of the American Society for Testing Materials.

350 **Test Voltage.** The dielectric strength of wire and cable insulation shall be tested at the factory by applying an alternating test voltage between the conductor and sheath or water.

351 THE MAGNITUDE AND DURATION OF THE TEST VOLTAGE should depend upon the dielectric strength and thickness of the insulation, the length and diameter of the wire or cable, and the assurance factor required, the latter in turn depending upon the importance of the service in which the wire or cable is employed.

The following test voltages shall apply unless a departure is considered necessary in view of the above circumstances. Rubber covered wires or cable for voltages up to 7 kv. shall be tested in accordance with the National Electric Code. Standardization for higher voltages for rubber insulated cables is not considered possible at the present time.

Varnished cambric and impregnated paper insulated wires or cables shall be tested at the place of manufacture for five (5) minutes in accordance with the table given below.

Different engineers specify different thickness of insulation for the same working voltages. Therefore at the present time the test kv. corresponding to working kv. given in the table below are based on the **minimum** thickness of insulation specified by engineers and operating companies.†

RECOMMENDED TEST KILOVOLTS CORRESPONDING TO OPERATING KILOVOLTS

E.M.F Operating kv.	E.M.F Test kv.	E.M.F. Operating kv.	E.M.F. Test kv.
Below 0.5	2.5*	5	14
0.5	3	10	25
1	4	15	35
2	6.5	20	44
3	9	25	53
4	11.5		

*The minimum thickness of insulation shallbe 1/16″

352 THE FREQUENCY OF THE TEST VOLTAGE shall not exceed 100 cycles per second, and should approximate as closely as possible to a sine wave. The source of energy should be of ample capacity.

353 **Where Ultimate Break-Down Tests** are required, these shall be made on samples not more than 6 meters (20 ft.) long. The maximum allowable temperature at which the test is made for the particular type of insulation and the particular working pressure, shall not be greater than the temperature limits given in **§ 345**.

354 **Multiple-Conductor Cables.** Each conductor of a multiple-conductor cable shall be tested against the other conductors connected together with the sheath or water.

†The Standards Committee does not commit itself to the principle of basing test voltages on working voltages, but it is not yet in possession of sufficient data to base them upon the dimensions and physical properties of the insulation.

INSULATION RESISTANCE

355 **Definition.** The insulation resistance of an insulated conductor is the electrical resistance offered by its insulation, to an impressed voltage tending to produce a leakage of current through the same.

356 Insulation resistance shall be expressed in megohms for a specified length (as for a kilometer, or a mile, or one thousand feet), and shall be corrected to a temperature of 15.5° C. using a temperature coefficient determined experimentally for the insulation under consideration.

357 Linear Insulation Resistance, or the insulation resistance of Unit Length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-thousand-feet.

358 **Megohms Constant.** The Megohms Constant of an insulated conductor shall be the factor " K " in the equation

$$R = K \log_{10} \frac{D}{d}$$

where R = The insulation resistance, in megohms, for a specified unit length.

D = Outside diameter of insulation.

d = Diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

359 **Test.** The apparent insulation resistance should be measured after the dielectric-strength test, measuring the leakage current after a one-minute electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained positive to the sheath or water.

360 **Multiple-Conductor Cables.** The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from such conductor to all the other conductors in multiple with the sheath or water.

CAPACITANCE OR ELECTROSTATIC CAPACITY

361 **Capacitance** is ordinarily expressed in microfarads. Linear Capacitance, or Capacitance per unit length, shall be expressed in Microfarads per unit length (kilometer, or mile, or one thousand feet) and shall be corrected to a temperature of 15.5° C.

362 **Microfarads Constant.** The Microfarads Constant of an insulated conductor shall be the factor " K " in the equation

$$C = \frac{K}{\operatorname{Log}_{10} \frac{D}{d}}$$

where C = the capacitance in microfarads per unit length.

D = the outside diameter of insulation.

d = the diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

363 **Measurement of Capacitance.** FOR LOW-VOLTAGE CABLE. The Capacitance shall be measured by comparison with a standard condenser. For long lengths of high-voltage cables, where it is necessary to know the true capacitance, the measurement should be made at a frequency approximating the frequency of operation.

364 **Paired Cables.** The capacitance shall be measured between the two conductors of any pair the other wires being connected to the sheath or ground.

365 **Electric Light and Power Cables.** The capacitance of low-voltage cables is generally of but little importance. The capacitance of high-voltage cables should be measured between the conductors, and also between each conductor and the other conductors connected to the lead sheath or ground.

366 **Multiple-Conductor Cables** (not paired). The capacitance of each conductor of a multiple-conductor cable shall be the capacitance measured from such conductor to all of the other conductors in multiple with the sheath or the ground.

STANDARDS FOR SWITCHES AND OTHER CIRCUIT CONTROL APPARATUS

SWITCHES

367 The following rules apply to **Switches** of above 600 volts. (For 600 volts and below, see National Electric Code.*)

Definition. A device for making, breaking, or changing connections in an electric circuit.

368 **Rating.**

(a) By amperes to be carried with not more than 30 °C. rise on contacts and current-carrying parts.

(b) By normal voltage of circuit on which it may be used.

369 **Performance and Tests.**

(a) **Heating Test** with rated current applied continuously until temperature is constant; ambient temperature 40 °C.

(b) **Dielectric Test** at 2½ times rated voltage plus 2000. See **§263.**

CIRCUIT BREAKERS

370 **Definition.** A device designed to open a current-carrying circuit without injury to itself. A circuit breaker† may be:

(a) An automatic circuit-breaker, which is designed to trip automatically under any predetermined condition of the circuit, such as an underload or overload of current or voltage.

(b) A manually tripped circuit-breaker, which is designed to be tripped by hand.

Both types of operation may be combined in one and the same device.

371 **Rating.**

(a) By normal current-carrying capacity.

(b) By normal voltage

(c) By amperes which it can interrupt at normal voltage of the circuit.

372 **Performance and Tests.** The heating test shall be made with normal current; in oil circuit breakers, same oil must be used for heating tests as for rupturing tests. Rise on contacts not to exceed 30 °C. Rise on tripping solenoids and accessory parts not to exceed 50 °C. Ambient temperature of reference, 40 °C.

373 **Dielectric Test.** Same as **§369.**

374 **Rupturing Test** must be made with the current specified under **§371** (c), and at normal voltage.

NOTE. Although circuit breakers should be considered as devices alone, no account being taken, in the rating, of the system on which they are to be used: yet in applying circuit breakers to any given service, it may be necessary to take into account the system on which they are to be used, with all its characteristics.

***By the term " Code " is meant " National Electrical Code " as recommended by the National Fire Protection Association.**

†These rules refer only to circuit breakers of above 550 volts. For 550 volts and below, see the National Electric Code.

Allowances must be made for the reactance, resistance, etc., of the circuit to be controlled, as these have a direct bearing on the maximum current flow.

In some systems it has been found that the pressure rises so high during switching, that higher insulation tests than that specified in **§369** should be given.

FUSES

(For circuits up to and including 600 volts, see National Electric Code)

375 **Definition.** An element designed to melt or dissipate at a predetermined current value and intended to protect against abnormal conditions of current.

NOTE. (The terminals, tubes, etc. which go with the fuse proper are included in the definition).

376 **Rating.** Fuses shall be rated at the maximum current which they are required to carry continuously and at the normal voltage of the circuit on which they are designed to be used.

Fuses may be divided into two classes:

(1) Those designed to protect the circuit and apparatus both against short circuit and against definite amounts of overload (*e.g.* fuses of the National Electric Code which open on 25 per cent overload).

(2) Those designed to protect the system only against short circuits; (*e.g.* expulsion fuses which blow at several times the current which they are designed to carry continuously). The line separating these two classes is not definitely fixed.

377 **Temperature.** Coils or windings (such as accompany fuses of the magnetic blowout type) should not exceed the limits set for machine coils having the same character of insulation. (See **§§188** to **192**). The highest temperature for the fuse proper should not exceed the safe limit for the material employed (*e.g.* the temperature of the fibre tube of an enclosed fuse should not exceed the safe limit for this material, but an open-link metal fuse may be run at any temperature which will not injure the fuse material; except that no application of the above rule shall contravene the National Electric Code).

378 **Test.** For fuses intended for use on circuits of small capacity, or in protected positions on systems of large capacity, see National Electric Code. For large power fuses intended for service similar to that required of circuit breakers, see **§370** to **374**, or the National Electric Code as far as the latter applies.

LIGHTNING ARRESTERS

379 **Definition.** A device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration.

380 **Rating.** Arresters shall be rated by the voltage of the circuit on which they are to be used.

Lightning arresters may be divided into two classes.

(a) Those intended to discharge for a very short time.

(b) Those intended to discharge for a period of several minutes.

NOTE. Complete standardization of these fuses above 600 volts according to the method of the National Electric Code is not advisable at this time, but is expected to be accomplished by an eventual extension of the National Electric Code. Until such extension is made, the following definitions and ratings may be followed.

381 **Performance and Tests.** Dielectric Test same as **§369.**

The resistance of the arrester at double potential and also at normal potential, determined by observing the discharge currents through the arrester.

(c) In the case of any arrester using a gap, a test shall be made of the spark potential on either direct-current or 60-cycle a-c. excitation.

(d) The equivalent sphere gap under disruptive discharge shall also be measured, using a considerable quantity of electricity.

(e) The endurance of the arrester to continuous surges shall be tested.

PROTECTIVE REACTORS

382 **Definition.** A reactor (See **§56**) for protecting circuits by limiting the current flow and localizing the disturbance under short-circuit conditions.

383 **Rating.**

(a) In kilovolt-amperes absorbed by normal current.

(b) By the normal current, frequency and line (delta) voltage for which the reactor is designed.

(c) By the current which the device is required to stand under short-circuit conditions.

384 **Performance and Tests.**

The Heat Test shall be made with normal current and frequency applied until the temperature is constant. The temperature should not exceed the safe limits for the materials employed. See **§§188 to 192.**

385 **Dielectric Test.** 2½ times line voltage plus 2000, for one minute, from conductor to ground.

NOTE. The reactor shall be so designed as to be capable of withstanding, without mechanical injury, rated current at normal frequency, suddenly applied.

RESISTOR OR RHEOSTAT

386 **Definition.** Any device heretofore commonly known as a resistance, used for operation or control. See National Electric Code. **(§55)**

INSTRUMENT TRANSFORMERS

387 **Definition.** A transformer for use with measuring instruments, in which the conditions in the primary circuit as to current and voltage are represented with high numerical accuracy in the secondary circuit.

Under this heading and for more general use:

(a) A current transformer is a transformer designed for series connection in its primary circuit with the ratio of transformation appearing as a ratio of currents.

(b) A potential (voltage) transformer is a transformer designed for shunt or parallel connection in its primary circuit, with the ratio of transformation appearing as a ratio of potential differences (voltages).

For further definitions relative to instrument transformers see **§112-114.** For the dielectric test of potential transformers, see **§254,** and for the dielectric test of current transformers, see **§263.** Further standards concerning instrument transformers are still under discussion.

STANDARDS FOR ELECTRIC RAILWAYS

DEFINITIONS

388 **Transmission System:** When the current generated for an electric railway is changed in kind or voltage, between the generator and the cars or locomotives, that portion of the conductor system carrying current of a kind or voltage substantially different from that received by the cars or locomotives, constitutes the ***transmission system.****

389 **Distribution System:** That portion of the conductor system of an electric railway which carries current of the kind and voltage received by the cars or locomotives, constitutes the ***distribution system.****

390 **Substation:** A substation is a group of apparatus or machinery which receives current from a transmission system, changes its kind or voltage, and delivers it to a distribution system.

RATING OF RAILWAY SUBSTATION MACHINERY

391 **Nominal Rating of Railway Substation Machinery:** The nominal rating of a substation machine shall be the Kv-a output at a stated power-factor input, which, having produced a constant temperature, may be increased 50 per cent for two hours without exceeding the standard ultimate temperature rise. In the case of frequency-changers, the power factor of the output shall also be stated.

Machines in substations subjected to extreme fluctuations of load, should be capable of carrying a load of twice their nominal rated load, for a period of five minutes, and should also be capable of carrying a load of three times the nominal rated load for one minute, without disqualifying them for continued service. These overloads shall be applied after a continuous run at nominal rated load.

392 **Continuous Rating.** The continuous rating of a substation machine shall be that load, at 100 per cent power factor, which it will carry continuously with a temperature rise not exceeding that set forth in **§188**, and fulfilling the other requirements set forth in these Rules and summarized in **§132**.

CONDUCTOR AND RAIL SYSTEMS.

393 **Contact Conductors.** That part of the distribution system other than the traffic rails, which is in immediate electrical contact with the circuits of the cars or locomotives, constitutes the contact conductors.

394 **Contact Rail:** A rigid contact conductor.

395 OVERHEAD CONTACT RAIL: A contact rail above the elevation of the maximum equipment line.†

396 THIRD RAIL: A contact conductor placed at either side of the track, the contact surface of which is a few inches above the level of the top of the track rails.

***These definitions are identical in sense, although not in words, with those of the Interstate Commerce Commission, as given in their Classification of Accounts for Electric Railways.**

†The contour which embraces cross-sections of all rolling stock under all normal operating conditions.

397 CENTER CONTACT RAIL: A contact conductor placed between the track rails, having its contact surface above the ground level.

398 UNDERGROUND CONTACT RAIL: A contact conductor placed beneath the ground level.

399 GAGE OF THIRD RAIL: The distance, measured parallel to the plane of running rails, between the gage line of the nearer track rail and the inside gage line of the *contact surface* of the third rail.

400 ELEVATION OF THIRD RAIL: The elevation of the contact-surface of the third rail, with respect to the plane of the tops of running rails.

401 STANDARD GAGE OF THIRD RAILS: The gage of third rails shall be not less than 26 inches (66 cm.) and not more than 27 inches (68.6 cm.).

402 STANDARD ELEVATION OF THIRD RAILS: The elevation of third rails shall be not less than 2¾ inches (69 mm.) and not more than 3½ inches (89 mm.).

403 THIRD RAIL PROTECTION: A guard for the purpose of preventing accidental contact with the third rail.

404 **Trolley Wire:** A flexible contact conductor, customarily supported above the cars.

405 **Messenger Wire or Cable:** A wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

406 **Classes of Construction:** Overhead trolley construction will be classed as *Direct Suspension* and *Messenger or Catenary Suspension.*

407 DIRECT SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

408 MESSENGER OR CATENARY SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *Simple Catenary, i.e.*, by primary messengers, or in *Compound Catenary, i.e.*, by secondary messengers.

409 SUPPORTING SYSTEMS shall be classed as follows:

410 SIMPLE CROSS-SPAN SYSTEMS: Those systems having at each support a single flexible span across the track or tracks.

411 MESSENGER CROSS-SPAN SYSTEMS: Those systems having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

412 BRACKET SYSTEMS: Those systems having at each support an arm or similar rigid member supported at only one side of the track or tracks.

413 BRIDGE SYSTEMS: Those systems having at each support a rigid member supported at both sides of the track or tracks.

414 STANDARD HEIGHT OF TROLLEY WIRE ON STREET AND INTERURBAN RAILWAYS: It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 feet (5.5m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 feet (6.4m.) above the top of rail, under conditions of maximum sag.

RAILWAY MOTORS

RATING

415 **Nominal Rating**: The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90 °C. at the commutator, and 75 °C. at any other normally accessible part after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance, shall not exceed 100 °C.*

416 The statement of the nominal rating shall also include the corresponding voltage and armature speed.

417 **Continuous Rating:** The continuous ratings of a railway motor shall be the inputs in amperes at which it may be operated continuously at $\frac{1}{2}$, $\frac{3}{4}$ and full voltage respectively, without exceeding the specified temperature rises (see §420), when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to define the system of ventilation which is used. In case motors are cooled by external blowers, the volume of air on which the rating is based shall be given.

418 **Maximum Input.** The subject of overloads for railway motors is under investigation.

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*This definition differs from that in the 1911 edition of the Rules, principally by the substitution of a kilowatt rating for the horse power rating and the omission of a reference to a room temperature of 25 °C. The horse power rating of a railway motor may, for practical purposes, be taken as $\frac{4}{3}$ of the kilowatt rating. On account of the hitherto prevailing practise of expressing mechanical output in horse-power, it is recommended that, for the present, the capacity be expressed both in kilowatts and in horse-power, a double rating, namely,

kw.————approx. equiv. h.p.————

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the capacity in horse power.

TEMPERATURE LIMITATIONS

419 **The allowable temperature** in any part of a motor in service will be governed by the kind of material with which that part is insulated. In view of space limitations, and the cost of carrying dead weight on cars, it is considered good practise to operate railway motors for short periods at higher temperatures than would be advisable in stationary motors. The following temperatures are permissible:

Operating Temperatures

Class of Material See §188.	Maximum Observable Temperature of windings when in continuous service.	
	By Thermometer See §174	By Resistance
A_2	85	110
B	100	130

For infrequent occasions, due to extreme ambient temperatures, it is permissible to operate at 15° higher temperature.

420 With a view to not exceeding the above temperature limitations the continuous ratings shall be based upon the **temperature rises** tabulated below:

Temperature Rises on Stand Test*

Class of Material See §188	Temperature Rises of windings	
	By Thermometer See §174	By Resistance
A_2	65	85
B	80	105

421 **Field-Control Motors.** The nominal and continuous ratings of field-control motors shall relate to their performance with the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

*The temperature rise in service may be very different from that on stand test. See §440 for relation between stand test and service temperatures, as affected by ventilation.

CHARACTERISTIC CURVES

422 **The Characteristic Curves** of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of a-c. motors, the power factor shall also be plotted as ordinates.

423 **Characteristic curves of direct-current motors** shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

424 **In the case of field-control motors,** characteristic curves shall be given for all operating field connections.

EFFICIENCY AND LOSSES

425 **The efficiency** of railway motors shall be deduced from a determination of the losses enumerated in **§426, 427, 428, 429** and **430.** (See also **§436** and **437.**)

426 **The copper loss** shall be determined from resistance measurements corrected to 75° C.

427 **The no-load core loss, brush friction, armature bearing friction and windage** shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above-mentioned, is equal to the product of the counter-electromotive force and the armature current.

428 The **core loss** in d-c. motors shall be separated from the friction and windage losses above described by measuring the power required to drive the motor at any given speed without gears, by running it as a series motor on low voltage and deducting this loss from the sum of the no-load losses at corresponding speed. (See **§437** for alternative method).

The friction and windage losses under load shall be assumed to be the same as without load, at the same speed.

The core loss under load shall be assumed as follows:

Core Loss in d-c. motors at Different Loads.

Per cent of Input at Nominal Rating	Loss as Per cent of No-load Core Loss
200	165
150	145
100	130
75	125
50	123
25 and under	122

Note:—With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no load losses at full and permanent field increased by the percentages given in the above table.

429 **The brush contact resistance loss** to be used in determining the efficiency, may be obtained by assuming that the sum of the drops at the contact surfaces of the positive and negative brushes is three volts.

430 The loss in gearing and axle bearings for single-reduction single-geared motors varies with type, mechanical finish, age and lubrication. The following values, based on accumulated tests, shall be used in the comparison of single-reduction single-geared motors.

Losses in Axle Bearings and Single-Reduction Gearings.

Per Cent of Input at Nominal Rating	Losses as Per Cent of Input
200	3.5
150	3.0
125	2.7
100	2.5
75	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

NOTE:—Further investigation may indicate the desirability of giving separate values of the losses for full and tapped fields, or slow- and high-speed motors.

ELECTRIC LOCOMOTIVES

431 **Rating.** Locomotives shall be rated in terms of the weight on drivers, nominal one-hour tractive effort, continuous tractive effort and corresponding speeds.

432 **Weight on Drivers.** The weight on drivers expressed in pounds shall be the sum of the weights carried by the drivers and of the drivers themselves.

433 **Nominal Tractive Effort:** The nominal tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their nominal (one-hour) rating.

434 **Continuous Tractive Effort.** The continuous tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their full voltage continuous rating, as indicated in **§417**.

In the case of locomotives operating on intermittent service, the continuous tractive effort may be given for ½ or ¾ voltage, but in such cases the voltage shall be clearly specified.

435 **Speed:** The rated speed, expressed in miles per hour, shall be that at which the continuous tractive effort is exerted.

APPENDIX I.

RAILWAY MOTORS

436 In comparing projected motors and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear, armature-bearing, brush-friction windage, and stray load losses.

Per cent of input at nominal rating	Losses as per cent of input
100 or over	5.0
75 "	5.0
60 "	5.3
50 "	6.5
40 "	8.8
30 "	13.3
25 "	17.0

437 The core loss of railway motors is sometimes determined by separately exciting the field and driving the armature of the motor to be tested, by a separate motor having known losses and noting the differences in losses between driving the motor light at various speeds and driving it with various field excitations.

438 **Selection of Motor For Specified Service**

The following information relative to the service to be performed is required in order that an appropriate motor may be selected.

(a) Weight of total number of cars in train (in tons of 2000 lb.) exclusive of electrical equipment and load.

(b) Average weight of load and durations of same, and maximum weight of load and durations of same.

(c) Number of motor cars or locomotives in train, and number of trailer cars in train.

(d) Diameter of driving wheels.

(e) Weight on driving wheels, exclusive of electrical equipment.

(f) Number of motors per motor car.

(g) Voltage at train with power on the motors—average, maximum and minimum.

(h) Rate of acceleration in m.p.h. per second.

(i) Rate of braking (retardation in m.p.h. per second).

(j) Speed limitations, if any (including slowdowns).

(k) Distances between stations.

(l) Duration of station stops.
(m) Schedule speed including station stops in m.p.h.
(n) Train resistance in pounds per ton of 2000 pounds at stated speeds.
(o) Moment of inertia of revolving parts, exclusive of electrical equipment.
(p) Profile and alignment of track.
(q) Distance coasted as a per cent of the distance between station stops.
(r) Time of layover at end of run, if any.

439 **Stand Test Method of Comparing Motor Capacity with Service Requirements:** When it is not convenient to test motors under actual specific service conditions, recourse may be had to the following method of determining temperature rise.

440 The essential motor losses affecting temperatures in service are those in the motor windings, core and commutator. The mean service conditions may be expressed as a close approximation, in terms of that continuous current and core loss which will produce the same losses and distribution of losses as the average in service.

A stand test with the current and voltage which will give losses equal to those in service, will determine whether the motor has sufficient capacity to meet the service requirements. In service, the temperature of an enclosed motor (**§ 97**), well exposed to the draught of air incident to a moving car or locomotive, will be from 75 to 90 per cent (depending upon the character of the service) of the temperature rise obtained on a stand test with the motor completely enclosed and with the same losses. With a ventilated motor (**§ 98** and **100**), the temperature rise in service will be 90 to 100 per cent of the temperature rise obtained on a stand test with the same losses.

441 In making a stand test to determine the temperature rise in a specific service, it is essential in the case of a self-ventilated motor (**§ 100**), to run the armature at a speed which corresponds to the schedule speed in service. In order to obtain this speed it may be necessary, while maintaining the same total armature losses, to change somewhat the ratio between the I^2R and core loss components.

442 **Calculation for Comparing Motor Capacity with Service Requirements.** The heating of a motor should be determined, wherever possible, by testing it in service, or with an equivalent duty cycle. When the service or equivalent duty cycle tests are not practicable, the ratings of the motor may be utilized as follows to determine its temperature rise.

443 The motor losses which affect the heating of the windings are as stated above, those in the windings and in the core. The former are proportional to the square of the current. The latter vary with the voltage and current, according to curves which can be supplied by the manufacturers. The procedure is therefore as follows:

444 (a) Plot a time-current curve and a time-voltage curve for the duty cycle which the motor is to perform, and calculate from these the root mean-square current and the equivalent voltage which with r.m.s. current will produce the average core loss.

445 (b) If the calculated r.m.s. service current exceeds the continuous rating, when run with average service core loss and speed, the motor is not sufficiently powerful for the duty cycle contemplated.

446 (c) If the calculated r.m.s. service current does not exceed the continuous rating, when run with average service core loss and speed, the motor is ordinarily suitable for the service. In some cases, however, it may not have sufficient thermal capacity to avoid excessive temperature rises during the periods of heavy load. In such cases a further calculation is required, the first step of which is to calculate the temperature rise due to the r.m.s. service current, and equivalent voltage.

Let $\left.\begin{aligned} t &= \text{temperature rise} \\ p_0 &= I^2R \text{ loss, kW.} \\ p_c &= \text{core loss, kW.} \end{aligned}\right\}$ with r.m.s. service current, and equivalent service voltage.

$\left.\begin{aligned} T &= \text{temperature rise} \\ P_0 &= I^2R \text{ loss, kW.} \\ P_c &= \text{core loss, kW.} \end{aligned}\right\}$ with continuous load current corresponding to the equivalent service voltage.

Then

$$t = T\,\frac{p_0 + p_c}{P_0 + P_c}\text{, approximately.}$$

447 (d) The thermal capacity of a motor is approximately measured by a coefficient equal to the ratio of the electrical loss in kW. at its nominal (one-hour) capacity, to the corresponding maximum observable temperature rise.

448 (e) Consider any period of peak load and determine the electrical losses in kilowatt-hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current and equivalent voltage. The excess loss divided by the co-efficient of thermal capacity will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and equivalent voltage, gives the total temperature rise. If the total temperature rise in any such period exceeds the safe limit, the motor is not sufficiently powerful for the service.

449 (f) If the temperature reached due to the peak loads does not exceed the safe limit, the motor may yet be unsuitable for the service, as the peak loads may cause excessive sparking and dangerous mechanical stresses. It is, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it may be considered suitable for the given duty cycle.

APPENDIX II.

*ILLUMINATION AND PHOTOMETRY.

460 **Luminous Flux** is radiant power evaluated according to its capacity to produce the sensation of light.

461 **The Luminous Intensity** of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

462 **Candle.** The unit of luminous intensity, maintained by the National Laboratories of France, Great Britain, and the United States. This unit, which is used also by many other countries, is frequently referred to as the international candle. The Hefner unit is 0.90 of the international candle.

463 **Candle-Power.** Luminous intensity expressed in candles.

464 **Lumen.** The unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of one candle-power.

465 **Illumination** on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then

$$E = \frac{dF}{dS},$$

or, when uniform,

$$E = \frac{F}{S}$$

466 **Lux.** A unit of illumination equal to one lumen per square meter. The C. G. S. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One millilumen per square centimeter (milliphot) is a practical derivative of the C. G. S. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots. The foot-candle is the commonly employed unit of illumination in English speaking countries.

467 **Exposure.** The product of an illumination by the time. Blondel has proposed the name "phot-second" for the unit of exposure in the C. G. S. system.

468 **Brightness, b, of an Element of a Luminous Surface from a Given Position** is the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per

*Sections 460 to 496, on Illumination and Photometry have been taken from the Publications of the Illuminating Engineering Society, after conference with its Committee on Nomenclature and Standards. (See reports of that Committee).

square centimeter of the projected area.

Defining equation:

Let θ be the angle between the normal to the surface and the line of sight, and dI the luminous intensity of the element.

Then

$$b = \frac{dI}{dS \cos\theta}$$

469 **Normal Brightness, b_0, of an Element of a Surface** (sometimes called **Specific Luminous Intensity**) is the luminous intensity of the element taken normally to the surface of the element, and is expressed in candles per square centimeter.

In practice, the brightness b of a luminous surface, or element thereof, is observed, and not the normal brightness b_0. For surfaces for which the cosine law of emission holds, the quantities b and b_0 are equal.

Defining equation:

$$b_0 = \frac{dI}{dS}, \quad \text{or, when uniform,}$$

$$b_0 = \frac{I}{S}$$

470 **Specific Luminous Radiation.** The luminous flux-density emitted by a surface, or the flux emitted per unit of emmissive area. It is expressed in lumens per square centimeter.

Defining equation:

Let E' be the specific luminous radiation.

Then, for surfaces obeying Lambert's cosine law of emission:—

$$E' = \pi b_0$$

471 **Coefficient of Reflection.** The ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection, the flux is reflected from the surface in all directions in accordance with Lambert's cosine law. In most practical cases, there is a superposition of regular and diffuse reflection.

472 **Coefficient of Regular Reflection** is the ratio of the luminous flux reflected regularly to the total incident flux.

473 **Coefficient of Diffuse Reflection** is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}$$

474 **Primary Luminous Standard.** A recognized standard luminous source reproducible from specifications.

475 **Representative Luminous Standard.** A standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

476 **Reference Standard.** A standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.

477 **Working Standard.** Any standardized luminous source for daily use in photometry.

478 **Comparison Lamp.** A lamp of constant but not necessarily known candle-power, against which a working standard and test lamps are successively compared in a photometer.

479 **Test Lamp,** in a photometer, a lamp to be tested.

480 **Performance Curve.** A curve representng the behavior of a lamp in any particular (candle-power, consumption, etc.) at different periods during its life.

481 **Characteristic Curve.** A curve expressing a relation between two variable properties of a luminous source, as candle power and volts, candle-power and rate of fuel consumption, etc.

482 **Mean Horizontal Candle-Power** of a lamp,—the average candle-power in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner; or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

483 **Mean Spherical Candle-Power** of a lamp,—the average candle-power of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

484 **Mean Hemispherical Candle-Power of a Lamp** (upper or lower),—the average candle-power of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

485 **Mean Zonal Candle-Power** of a lamp,—the average candle-power of a lamp over a given zone. It is equal to the total luminous flux emitted by the lamp in that zone divided by the solid angle of the zone.

486 **The Spherical Reduction-Factor** of a lamp

$$= \frac{\text{mean spherical candle-power}}{\text{mean horizontal candle-power}}$$

487 The **Spherical Reduction-Factor** should be used only when properly determined for the particular type and characteristics of each lamp. The spherical reduction-factor permits of substantially accurate comparisons being made between the total lumens, or mean spherical candle-powers of different types of incandescent lamps, and may be used in the absence of proper facilities for direct measurement of the total lumens or mean spherical candle-power.

488 **The Specific Output of Electric Lamps** is properly stated in terms of lumens per watt at lamp terminals. The use of the term efficiency in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, the input should be taken to include both that in the lamp and that in the auxiliary devices. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

489 **The Specific Consumption** of an electric lamp is its watt consumption per lumen. "Watts per candle" is a term used commercially in connection with incandescent lamps, and denotes, watts per mean horizontal candle-power.

490 **Photometric Tests** in which the results are stated in candle-power should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made in the measurement of lamps with reflectors, the results should always be given as "apparent candle-power" at the distance employed, which distance should always be specifically stated.

491 **Basis for Comparison.** Either the total flux of light in lumens, or the mean spherical candle-power, should always be used as the basis for comparing various luminous sources with each other, unless there is a clear understanding or statement to the contrary.

492 **Incandescent Lamps, Rating.** It is customary to rate incandescent lamps on the basis of their mean horizontal candle-power; but in comparing incandescent lamps in which the relative distribution of luminous intensity differs, the comparison should be based on their total flux of light measured in lumens, or on their mean spherical candle-power.

493 **Life Tests.** Lamps of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life-test results, in order to be compared must be either conducted under, or reduced to, comparable conditions of operation.

494 In **Comparing Different Luminous Sources,** not only should their candle-power be compared, but also their relative form, brightness, distribution of illumination and character of light.

495 **Symbols.**

Photometric magnitude	Name of unit	Symbols
1. Luminous flux	Lumen	F, Ψ
2. Luminous intensity	Candle	I, Γ
3. Illumination	Phot., foot-candle, lux	E, β
4. Exposure	Phot-second	Et
5. Brightness	Apparent candles per sq. cm. Apparent candles per sq. in.	b
6. Normal brightness	Candles per sq. cm. Candles per sq. in.	b_0
7. Specific luminous radiation	Lumens per sq. cm. Lumens per sq. in.	E' β'
8. Coefficient of reflection.		m

496 In view of the fact that the symbols heretofore proposed conflict in some cases with symbols adopted for electric units by the International Electrotechnical Commission, it is proposed that where the possibility of any confusion exists in the use of electric and photometric symbols, an alternative system of symbols for photometrical quantities should be employed. These should be derived exclusively from the Greek alphabet, for instance:

Luminous intensity............................ Γ
Luminous flux.................................. Ψ
Illumination..................................... β

APPENDIX III.

STANDARDS FOR TELEPHONY AND TELEGRAPHY

TENTATIVE DEFINITIONS*

501 After careful consideration it does not seem that the time is yet ripe for a formal standardization of terms and definitions used in telephony and telegraphy. Many of the terms commonly employed are used in more than a single way, and conversely, many pieces of apparatus and many constants which are essentially identical from a physical standpoint have been and are known by more than one designation.

502 **Damping of a Circuit.** The damping, at a given point, in a circuit from which the source of energy has been withdrawn, is the progressive diminution in the effective value of electromotive force and current at that point resulting from the withdrawal of electrical energy.

503 **Damping Constant.** The damping constant of a circuit depends upon the ratio of the dissipative to the reactive component of its impedance or admittance.

Applied to the admittance of a condenser or other simple circuit having capacity reactance, the damping constant for a harmonic electromotive force of given frequency is the ratio of the conductance of the condenser or simple circuit at that frequency to twice the capacity of the condenser at the same frequency.

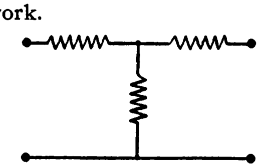
Applied to the reactance of a coil or other simple circuit having inductive reactance, the damping constant for a harmonic current of given frequency is the ratio of the resistance of the coil or circuit at that frequency to twice the inductance at the same frequency.

504 **Equivalent Circuit.** An equivalent circuit is a simple network of series and shunt impedances, which, at a given frequency, is the approximate electrical equivalent of a complex network at the same frequency and under steady state conditions.

NOTE: As ordinarily considered, the simple networks as defined, are the electrical equivalents of complex networks only with respect to definite pairs of terminals, and only as to sending-end impedances, and total attenuation. A further requirement is that the only connections between the pairs of terminals are those through the network itself.

505 **"T" Equivalent Circuit.** A "T" equivalent circuit is a triple star or "Y" connection of three impedances externally equivalent to a complex network.

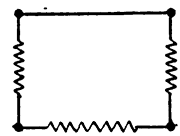
Symbol:



*Comments or suggestions should be forwarded to the Chairman of the Sub Committee on Telephone and Telegraph Standards.

506 **"U" Equivalent Circuit.** A "U" equivalent circuit is a delta connection of three impedances externally equivalent to a complex network. It is also called a "Π" equivalent circuit.

Symbol:



IMPEDANCE

507 **Mutual Impedance.** The mutual impedance, for alternating currents, between a pair of terminals and a second pair of terminals of a net work, under any given condition, is the negative vector ratio of the electromotive force produced between either pair of terminals on open circuit to the current flowing between the other pair of terminals.

508 **Self Impedance.** The self impedance between a pair of terminals of a network, under any given condition, is the vector ratio of the electromotive force applied across the terminals to the current produced between them.

LINE CHARACTERISTICS

509 **Characteristic Impedance.** Characteristic impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current upon line of infinite length and uniform structure, or of periodic recurrent structure.

NOTE: In telephone practice, the terms (1) line impedance, (2) surge impedance, (3) iterative impedance, (4) sending-end impedance, (5) initial sending-end impedance, (6) final sending-end impedance, (7) natural impedance and (8) free impedance, have apparently been more or less indefinitely and indiscriminately used as synonyms with what is here defined as "characteristic impedance."

510 **Sending-End Impedance.** The sending-end impedance of a line is the vector ratio of the applied electromotive force to the resulting steady-state current at the point where the electromotive force is applied.

NOTE: See note under "Characteristic Impedance." In case the line is of infinite length of uniform structure or of periodic recurrent structure, the sending-end impedance and the characteristic impedance are the same.

511 **Propagation Constant.** The propagation constant per unit length of a uniform line, or per section of a line of periodic recurrent structure, is the natural logarithm of the vector ratio of the steady-state currents at various points separated by unit length in a uniform line of infinite length, or at successive corresponding points in a line of recurrent structure of infinite length. The ratio is determined by dividing the value of the current at the point nearer the transmitting end by the value of the current at the point more remote.

512 **Attenuation Constant.** The attenuation constant is the real part of the propagation constant.

513 **Wave-Length Constant.** The wave-length constant is the imaginary part of the propagation constant.

LINE CIRCUITS

514 **Ground-Return Circuit.** A ground-return circuit is a circuit consisting of one or more metallic conductors in parallel, with the circuit completed through the earth.

515 **Metallic Circuit.** A metallic circuit is a circuit of which the earth forms no part.

516 **Two-Wire Circuit.** A two wire circuit is a metallic circuit formed by two paralleling conductors insulated from each other.

517 **Superposed Circuit.** A superposed circuit is an additional circuit obtained from a circuit normally required for another service, and in such a manner that the two services can be given simultaneously without mutual interference.

518 **Phantom Circuit.** A phantom circuit is a superposed circuit, each side of which consists of the two conductors of a two-wire circuit in parallel.

519 **Side Circuit.** A side circuit is a two-wire circuit forming one side of a phantom circuit.

520 **Non-Phantomed Circuit.** A non-phantomed circuit is a two-wire circuit, which is not arranged for use as the side of a phantom circuit.

521 **Simplexed Circuit.** A simplexed circuit is a two-wire telephone circuit, arranged for the super-position of a single ground-return signalling circuit operating over the wires in parallel.

NOTE: In view of the use of the term " Simplex Operation " in telegraph practise, it is felt that the designation " Simplexed Circuit " as applied to the arrangement described is not a happy one.

522 **Composited Circuit.** A composited circuit is a two-wire telephone circuit, arranged for the super-position on each of its component metallic conductors, of a single independent ground-return signalling circuit.

523 **Quadded or Phantomed Cable.** A quadded (or phantomed) cable is a cable adapted for the use of phantom circuits.

NOTE: The type of cable here defined has frequently been designated as " Duplex Cable "—a term which is objectionable, both on account of its lack of description and its widely different use in telegraph practice.

LOADING

524 **Loaded Line.** A loaded line is one in which the normal inductance of the circuit has been altered for the purpose of increasing its transmission efficiency for one or more frequencies.

525 **Series Loaded Line.** A series loaded line is one in which the normal inductance has been altered by inductance serially applied.

526 **Shunt Loaded Line.** A shunt loaded line is one in which the normal inductance of the circuit has been altered by inductance applied in shunt across the circuit.

527 **Continuous Loading.** A continuous loading is a series loading in which the added inductance is uniformly distributed along the conductors.

528 **Coil Loading.** A coil loading is one in which the normal inductance is altered by the insertion of lumped inductance in the circuit at intervals. This lumped inductance may be applied either in series or in shunt.

NOTE: As commonly understood, coil loading is a series loading, in which the lumped inductance is applied at uniformly spaced recurring intervals

529 **Microphone.** A contact device designed to have its electrical resistance directly and materially altered by slight differences in mechanical pressure.

530 **Relay.** A relay is a device by means of which contacts in one circuit are operated under the control of electrical energy in the same or other circuits.

531 **Resonance.** Resonance of a harmonic alternating current of given frequency, in a simple series circuit, containing resistance, inductance and capacity, is the condition in which the positive reactance of the inductance is numerically equal to the negative reactance of the capacity. Under these conditions, the current flow in the circuit with a given electromotive force is a maximum.

532 **Retardation Coil.** A retardation coil is a reactor (reactance coil) used in a circuit for the purpose of selectively reacting on currents which vary at different rates.

NOTE: In telephone and telegraph usage the terms "impedance coil," "inductance coil," choke coil" and "reactance coil" are sometimes used in place of the term "retardation coil."

533 **Skin Effect.** Skin effect is the phenomenon of the non-uniform distribution of current throughout the cross-section of a linear conductor, occasioned by variations in the intensity of the magnetic field due to the current in the conductor.

534 **Telephone Receiver.** A telephone receiver is an electrically operated device designed to produce sound waves or vibrations which correspond in form to the electromagnetic waves or vibrations actuating it.

535 **Telephone Transmitter.** A telephone transmitter is a sound-wave or vibration-operated device designed to produce electromagnetic waves or vibrations which correspond in form to the sound waves or vibrations actuating it.

TRANSFORMERS

536 **The Coefficient of Coupling of a Transformer.** The coefficient of coupling of a transformer at a given frequency is the vector ratio of the mutual impedance between the primary and secondary of the transformer, to the square root of the product of the self-impedances of the primary and of the secondary.

537 **Repeating Coil.** A term used in telephone practice meaning the same as transformer, and ordinarily a transformer of unity ratio.

RADIO

538 **Acoustic Resonance Device.** One which utilizes in its operation mechanical or other resonance to the audio frequency of the received impulses.

539 **Antenna.** A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

540 **Atmospheric Absorption.** That portion of the total loss of radiated energy due to atmospheric conductivity.

541* **Audio Frequencies.** The normally audible frequencies lying between 20 and about 20,000 cycles per second. (See also Radio Frequencies.)

542 **Capacity Coupler.** An apparatus which electrostatically joins portions of two circuits, and thereby permits the transfer of electrical energy between these circuits through the action of electric forces.

543 **Coefficient of Coupling.** See **536** above.

544* **Conductive Coupler.** An apparatus which magnetically and electrically joins two circuits having a common conductive portion (also known as a Direct Coupler).

545* **Counterpoise.** A system of electrical conductors forming one plate of a condenser, the other plate of which is the ground. For alternating current, it may be used to replace a direct connection to ground.

546 **Damping of a Circuit.** See No. **502.**

547 **Damping Factor of a Simple Circuit.** The ratio of the effective resistance of that circuit to twice the effective inductance at any frequency. (The reciprocal of a time.) This term applies only to circuits capable of carrying free alternating currents. The same quantity is also called the "damping coefficient," or "damping constant." (See **503** above).

548 **Detector.** That portion of the receiving apparatus which, connected to a circuit carrying currents of radio-frequency, and in conjunction with a self-contained or separate indicator, translates the radio-frequency energy into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio frequency energy, or by means of the control of local energy by the energy received.

549 **Electromagnetic Wave.** A progressive disturbance characterized by the existence on the wave front of electric and magnetic forces acting in directions which are perpendicular to each other and to the direction of propagation of the wave.

550 **Forced Alternating Current*.** A current produced in any circuit by the application of an alternating electromotive force.

551* **Free Alternating Current.†** A current produced by an electrical impulse in a circuit having capacity, inductance, and *less* than the critical resistance.

*In power applications termed simply an alternating current.
†In " " termed simply an oscillating current. See § 5.

552 **Critical Resistance of a Free Alternating Current Circuit.** Twice the square root of the ratio of the inductance of that circuit to the capacity of that circuit both expressed in practical units. This term applies only to circuits capable of carrying free alternating currents.

553 **Group Frequency.** The number of distinguishable alternating current groups occurring per second in an electrical circuit.

NOTE 1: The group referred to above is, in general mainly a free alternating current which is substantially damped to extinction before the beginning of the following group or train.

NOTE 2: The acoustic pitch of the note in the receiving station is, in general, determined by the group frequency at the transmitting station.

NOTE 3: The term "Group Frequency" replaces the term "Spark Frequency."

554* **Inductive Coupler.** An apparatus which magnetically joins portions of two electric circuits.

555 **Linear Decrement of a Circuit Containing a Resistance Element Equivalent to a Spark.** The difference of successive current amplitudes in the same direction divided by the larger of these amplitudes. (In circuits containing such an element, not the ratio of successive current amplitudes, but their difference is constant, and characteristic of the damping.)

556 **Logarithmic Decrement.** The logarithmic decrement of oscillations in a circuit containing inductance, capacity, and constant resistance when no electrical energy is being added to the circuit, is the natural logarithm of the ratio of successive maximum instantaneous current amplitudes in the same direction. It is also approximately equal, for small decrements, to one half the ratio of the decrease in electrical energy in the circuit during one complete current cycle to the total energy present in the circuit at the middle of the cycle.

NOTE: Logarithmic decrements are standard for a complete period or cycle.

557* **Radio Frequencies.** Those above 20,000 cycles per second. (See also Audio Frequencies).

NOTE: It is not implied that radiation cannot be secured at lower frequencies and the distinction from audio frequencies is merely one of definition.

558 **Resonance to an Alternating Current.** See **531** above.

559 **A Resonance Curve** gives the power, current, or voltage at various frequencies of excitation as a function of those frequencies. or of the corresponding wave lengths.

560 **A Wave-Length Resonance Curve** is one wherein the abscissas are ratios of specified wave lengths to the resonant wave length, and the ordinates are ratios of the energy (or square of the current) at corresponding specified wave lengths to the energy (or square of the current) at the resonant wave length. It is advantageous to have the scales of ordinates and abscissas equal.

561 **A Frequency Resonance Curve.** One wherein the abscissas are ratios of specified frequencies to the resonant frequency, and the ordinates are ratios of the energy (or square of the current) at corresponding specified frequencies to the energy (or square of the current) at the resonant frequency. The scales of ordinates and abscissas equal.

562 **A Standard Resonance Curve** unless otherwise specified, is assumed to be a wave-length resonance curve.

563 **Selecting.** The process of adjusting an element driven by a plurality of simultaneous impulses, until the ratio of desired response to undesired response is a maximum.

564 **Sustained Radiation** consists of electromagnetic waves of constant amplitude (such as are emitted from an antenna in which a forced alternating current flows.)

565* **Tuning.** The process of securing the maximum indications by adjusting the time period of a driven element. (In transmitter or receiver.)

566* **A Wave-Length Meter Commonly called a Wave-Meter,** is a radio frequency measuring instrument calibrated to read wave lengths.

567 **Rating.** 1. All radio transmitting sets shall be rated in actual power output measured in the antenna.

NOTE: The group or audio frequency of the note of the station should be stated as well, (except for sustained wave sets, wheret hat characteristic should be mentioned).

2. The over-all efficiency of a radio transmitting station shall be the ratio of the actual power output as measured in the antenna to the power input supplied to the first piece of electrical machinery which is definitely a part of the radio equipment.

568 **Decremeter.** An instrument for measuring the logarithmic decrement of a circuit or of a train of electromagnetic waves.

Sections **538** to **568**, inclusive, have been inserted after conference with the Standards Committee of the Institute of Radio Engineers. The Sections whose numbers are marked with an asterisk have been subjected to criticism, and are under discussion.

APPENDIX IV.

BIBLIOGRAPHY OF LITERATURE RELATING TO ELECTRICAL ENGINEERING STANDARDIZATION

Engineering Manual of the American Electric Railway Engineering Association.

Standardization Rules of the Electric Power Club, 1913.

Report of the Committee on Standardization of the Institute of Radio Engineers, 1913.

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